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# Variations in water quality in rural Iowa wells

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Variations in water

quality in rural

Iowa wells

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# INTRODUCTION

In many parts of Iowa, the rural farm or domestic well is usually a shallow (20-130 feet deep), dug, augered, drilled, or driven type well, located in surficial aquifers. Throughout the state thousands of these wells are in use and must consistently offer a safe potable supply of water. In past years, surveys and sampling programs of shallow wells in several Iowa counties have indicated a widespread occurrence of polluted ground water. More specifically, these surveys have sampled many rural wells which upon testing show high coliform bacteria or nitrate nitrogen levels. When test results show high coliform counts (numbers greater than 1 coliform per 100 ml sample by E.P.A. criteria) or high nitrate level (maximum permissible level at 10 mg/l as N) there is a higher risk of human disease propagation. So the exclusion of these indicator sources is of public health significance when controlling pollutants.

Contamination of shallow ground water aquifers has presented a serious problem for those actually using the water as well as to those faced with developing and managing the nation's water resources. These problems are important because:

1) Shallow aquifers, which are important sources of untreated water, are the most susceptible to contamination

due either from man's activities or from natural sources because of the influence of pumping, drilling, or excavating;

2) Once an aquifer has been contaminated it is usually economically unfeasible and often physically impossible to reclaim it; and

3) The public does not generally understand the principles involved in ground water contamination or are not informed about them.

Upon recognition of the potentially serious consequences available in the state of Iowa for the outbreaks of disease, an attempt must be made to limit the sources of pollution from entering the ground water. The water well alone provides many pathways for pollutants to directly enter the water supply. Also it would be useful to identify and evaluate the highly variable character of the contaminants. By evaluating and establishing minimum standards for well construction practices (in this case meaning all aspects of well construction, location, completion, etc.) the sanitary protection of well water supplies can be safeguarded from the pollution sources.

The primary objective behind this research study was to investigate the occurrence of rural well water contamination and the possible correlation of well water quality with well construction practices.

The investigation into the contamination of rural well water supplies included:

1) a review of studies showing the magnitude of rural well water problems throughout Iowa,

2) a testing program utilizing several Iowa wells where samples of total coliform bacteria, fecal streptococci, and nitrite + nitrate nitrogen tests are taken over time, and

3) an analysis of the relationship between water quality variations in wells and climatological data.

Relating the occurrence of contaminants to the well construction methods involves investigation into the following areas:

1) the significance of well structure on the sanitary protection of the well,

2) the impact of well location on water quality, and

3) the importance of the well completion step on safeguarding the well.

Upon reading this report one should be able to grasp the nature of the problems that plague water wells, as well as the relationship of pollutants to ground water supplies.

# LITERATURE REVIEW

Ground water, one of the world's valuable resources, is defined as that part of the subsurface water at depths where all the "pores" in the rock material are filled with water. These underground natural reservoirs have many advantages: dependability as a source of water, (especially at times of surface droughts); a large existing storage supply for easy accessibility; and relatively cheap development costs for usage. The amount of ground water that can safely be used depends on the quantity of water stored in the aquifer (according to aquifer conditions, porosity, and permeability) and the climate and geological conditions that effect the replenishment of the ground water supplies. This recharge of water relates ground water to its role in the hydrologic cycle. As precipitation falls, a portion enters the soil profile and infiltrates downward by capillary action or gravity until a saturated zone is reached. Then the water moves laterally amounting to only a few centimeters per day in sand and fine grain rocks or as much as several thousand meters per day in fissured geologic formations, to a point of natural or artificial discharge (17).

As Figure 1 shows, the movement of water, as ground water, in its role in the hydrologic cycle provides a link connecting water infiltration (soil moisture) and

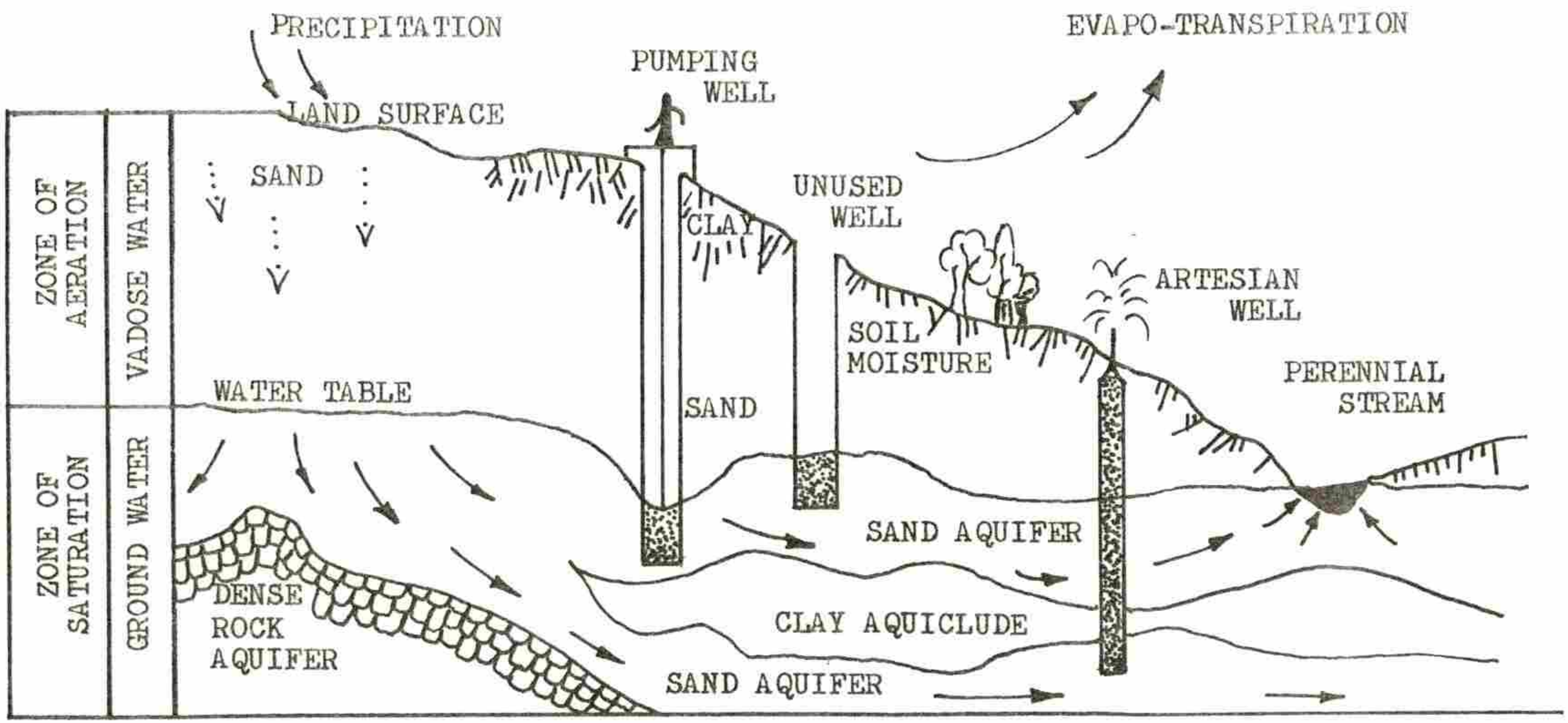


Figure 1. Flow of ground water in the hydrologic cycle (11)

streamflow. This ground water cycle represents a large quantity of water available for use as it exists in water tables or aquifers.

Ground water represents roughly four million cubic km. total volume on earth. This amount is less than 0.3% of all water on the earth; but studies by the U.S. Geologic Survey indicates over 97% of our fresh water resources are located underground (23). This vast ground water reserve must be managed, in terms of quantity and quality, to provide a continuous supply of potable water. Ground water supplied in the United States totals over 21.4% in 1970 of the fresh water withdrawn, with 34% to the public supply and 36% to crop irrigation. Also, over 80% of the water going to domestic/rural supplies is ground water with minimal or no treatment (2).

Most ground water aquifers have a multi-barrier natural defense system that may remove or degrade contaminants (7). The top few inches of the soil contains a biosphere of microorganisms which offer a living filter and biological oxidizer to greatly reduce the pollutant load. Also the ground media processes of sedimentation, dilution, sorption, ion exchange, and various physical processes aid this natural defense system (3). These phenomena are controlled by the physical environment, structure, mineralogy, and hydraulic character of the earth's materials.

Ideally, this "natural protection" of ground water would insure a continuous potable supply of water. Although more than 60 million individuals in the United States rely upon the absence of microbial pathogens in the marginally treated or untreated ground water supplies, an analysis of reported waterborne disease outbreaks for the period of 1946-1970 shows that contaminants of ground water supplies were responsible for over 50% of the outbreaks (6). For example, Clark and Chang (5) in 1959 listed the following epidemics of infectious Hepatitis caused by contaminated ground water:

| | | |
|---|---|---|
| 1944 | 350 cases- | driven well polluted by a cesspool 75 feet away |
| 1952 | 22 cases- | drilled well polluted by cesspool 50 feet away |
| 1952 | 102 cases- | spring polluted from a broken sewer, over 50 feet |
| 1956 | 18 cases- | well polluted by septic tank effluent |
| 1956 | 46 cases- | well polluted by a river over 50 feet away |

Also there is a great variation in the natural chemical constituents of ground water (19, 35). Many of the constituents such as sodium, sulfate, calcium, magnesium, iron, nitrate, boron, and arsenic are toxic or objectional to man and limit the range of ground water use. For instance, the nitrate nitrogen level in ground water will rise if the well is not sealed from surface runoff of livestock wastes. This fact is well demonstrated by evidence of the disease methemoglobinemia in infants, where since 1945 about 2,000 cases have been reported in the United States and Europe (26, 27).

These and many other well documented cases indicate that ground water contamination by pollutants actually does occur. This indicates a direct contradiction to the "natural protection" of soils. In actual soil conditions, the removal of contaminants is not perfect.

There are three basic methods by which ground water becomes polluted:

1) the natural filtering system of vegetation, soil, silt, sand, gravel, and rock that protect ground water is by-passed by pollutant substances,

2) the natural filtering system is overwhelmed by a contaminant of high concentration beyond its capacity to handle them, and

3) the hydraulic balance in the subsurface is altered so that polluted substances move to, within, or between aquifers to change water quality (9, 7).

## Biological Contamination of Ground Water

The determination of the organisms present in a ground sample is difficult to obtain accurately. Recent investigations have indicated the presence of several types of organisms, thus proving that subsurface regions are not totally hostile to microbial life and further linking ground water as a media of disease producing organisms (25). These microorganisms include: sulfur-reducing bacteria, *Thiobacillus*, *Pseudomonas*, *Methanonenas*, *Mycobacterium*, *Actinomyces*, *Pseudobacteriu*, *Desulfovibrio*, *Shigella flexneri*, *S. Somnei*, and *Salmonella typhi*.

The determination of bacteriological quality of ground water is essential so that water criteria standards may be set. Several methods for the indication of pollution are not reliable when related to ground water samples (24). The coliform test shows a high degree of correlation with the presence of pathogens in surface waters, but due to the interferences and media limitations of subsurface areas the application to ground water supplies is questionable. Other improved methods must be obtained so that reliable treating for pathogens in ground water is possible.

The use of fecal streptococcal organisms may give a more reliable indication of pathogens. This test determines the presence of certain fecal bacteria that are more closely linked with animal enteric pathogens (18).

Numerous documented reports, between 1946 and 1970, indicate that contamination of ground waters was responsible for many outbreaks of waterborne diseases. Table 1 summarizes the extent of ground water pollution by listing several of the disease outbreaks. Studies indicate strongly that microbial populations are both possible and probable in most subsurface habitats (1, 25). The significance of such activity on the pollution of ground water may be beneficial or detrimental depending on the species, environment, and man's interference. Also, this suggests that once populations are introduced into ground water regions they may persist for some period.

Biological activity occuring in the subsurface regions is of considerable importance in determining the fate and effect of pollutants in ground water. Available literature, although somewhat limited, points out factors pertaining to the development of biological systems or suitable habitats for many microbial species (25). The biological activity which occurs or can be expected to occur is important in the effects of bacterial and viral pollutant growth and also in the biological alteration of these pollutants.

Once the bacterial contaminant reaches the soil matrix (from such sources as cesspools, abandoned wells, etc.) most biological processes involve the destruction of the pollutant. The mechanisms include: 1) the pollutant's inability to adjust to environmental changes, 2) the oxygenation and nitrification processes, 3) destruction by pre-existing bacteria, and 4) the natural die-away rate of bacteria in the soil (15, 31). The survival of most indicator organisms (including coliforms and fecal bacteria) is normally less than three weeks as the organism count decreases over time (16). This fact makes it difficult to predict a contaminated ground water since some bacteria and virus may survive up to five years under certain conditions (31).

In addition to the "natural" processes of microbial destruction there are "physical" mechanisms of removal based on relating the travel of pollutants through the soil and water-bearing formations. These mechanisms include the mechanical processes of filtration (dependent on the pore spaces of soil particles and size of pollutants), and sedimentation (depending on the size of the suspended material and the rate of water flow) (22). This soil clogging is the physical processing that increases the resistance of pollutant flow due to the reduction in soil pore spaces. Figure 2 relates this natural protection by showing the concentration of coliforms (an indicator of organic pollution) found at various depths of Hanford sandy loam soils.

The mechanical straining and clogging of the soils effectively removes microorganisms and disease pathogens. It is now accepted that great numbers of these pollutants

Table 1. Summary of waterborne disease cases (1946-1970), according to type illness and water supply system (1)

Water-Supply Systems

| Illness | Private | Public |
|---|---|---|
| Bacterial associated: | | |
| Typhoid | 507 | 103 |
| Salmonellosis | 118 | 16,612 |
| Shigellosis | 1,616 | 5,784 |
| Enteropathogenic | 188 | 0 |
| Leptospirosis | 0 | 9 |
| Gastroenteritis | 8,970 | 36,285 |
| Tularemia | 6 | 0 |
| Viral associated: | | |
| Infectious Hepatitis | 1,094 | 739 |
| Poliomyelitis | 0 | 16 |
| Protozoan associated: | | |
| Amebiasis | 50 | 25 |
| Giardiasis | 19 | 157 |

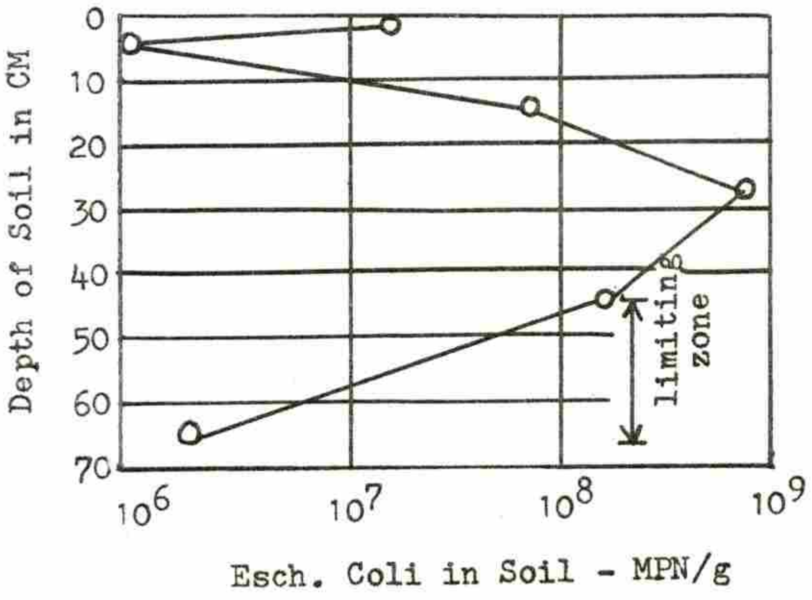


Figure 2. Concentration of coliform organisms with depth in Hanford soil (31)

are removed by percolation through a few feet of sand and have seldom been found after five feet of travel (31).

As previously mentioned, the movement of biological contaminants in a soil profile is limited to the upper five feet, due to the "natural protection" mechanisms. This downward movement pertains to the ideal soil conditions and geologic formations. Ground water contamination may result from the by-passing of such "filterability", as seen from contamination due to subsurface excavations, wells, septic tanks, sewage ponds, etc. The small size of many of the biological pollutants, like viruses, with a size of 0.02 microns, enables them to penetrate and move with the flow of subsurface water to ranges of 50 to 100 feet (31). Also, geologic fissures, limestone crevasses, and bedrock faults permit contaminants to travel rapidly for great distances. For example, field studies (1) performed under conditions of fractured bedrock, found that at certain test sites a tracer bacterium travelled a horizontal distance (with the water flow) of 94 feet in 24 hours. The possibility exists, under certain geologic conditions, that organic pollutants may travel several hundred feet from the source of pollution. Such movement requires that ground water must be restricted in usage by distance from pollution sources until natural die-off of the bacteria or virus or filterability removes the

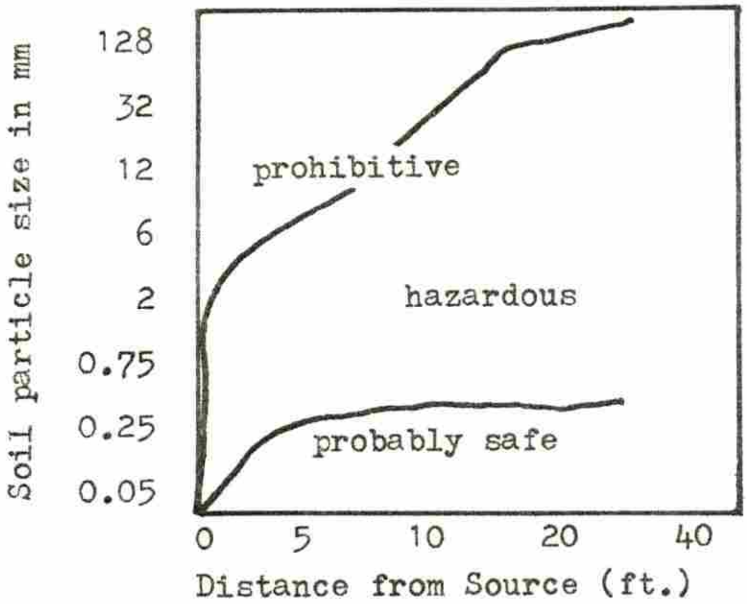


Figure 3. Biological pollution travel in non-saturated materials (31)

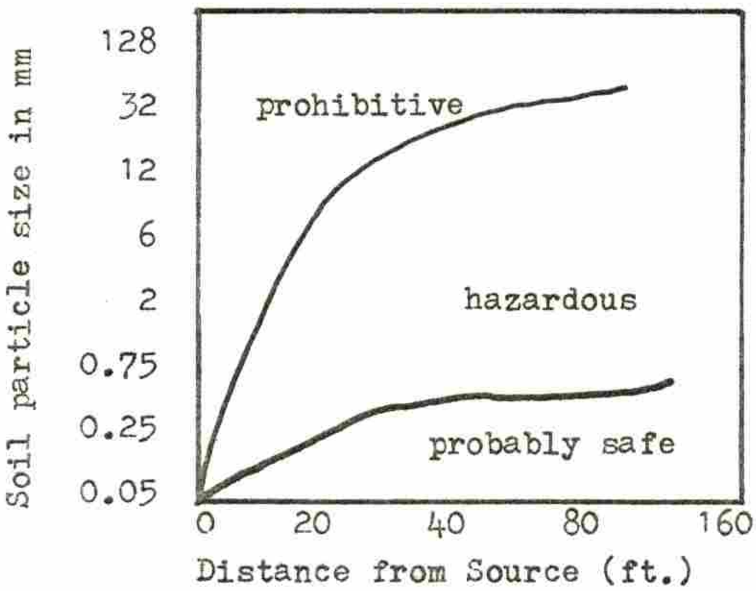


Figure 4. Biological pollution travel with ground water (31)

contaminants.

The problem of determining "safe" distances between ground water supplies and pollution sources is somewhat difficult because of the nature of local geologic conditions in determining pollution fate. Figures 3 and 4 show some general guidelines to follow. The "safe" distances are the minimum required distances between the pollutant source and water withdrawn as a function of the soil particle size. The factors that should be determined to predict safe distances include:

1) the character and location of the source of potential or existing contamination,

2) geologic and hydraulic characteristics of the materials at the land surface, water table, confining layer, and aquifer, and

3) seasonal depths to water, its direction and rate of movement, and effects from well pumping (16).

## Nitrogen Contamination of Ground Water

Nitrogen is a problem of increasing magnitude from the standpoint of ground water quality, in terms of public health and economic considerations. Nitrogen in ground water is of public health significance as an indicator of pollution and also a direct cause of infant methemoglobinemia when consumed in the form of nitrates (8). The principal area of concern is the recognition of nitrogen sources and then taking steps to eliminate their pollution potential.

The basic cause of nitrogen contamination is the release of nitrogen containing substances at or near the surface of the earth in direct relation to man's activities (39). Frequently, in rural areas these nitrogen pollutants originate from septic tank effluents, privies, sanitary landfills, leaking sewers, irrigation systems, animal feedlots, accidental spills of fertilizer, agricultural activities, and other similar sources (21, 29). These high nitrogen, point or non-point, pollution sources are of potentially serious consequences since many rural supplies are located near them.

The nitrogen pollutants entering the soil matrix usually reach the surficial ground water supply as either nitrate ($NO_3^-$) or ammonium ion ($NH_4^+$), depending on the amount of oxygen available (20). The nitrate level in ground water is of the most significance (in terms of quantity and detrimental effects) so that most of the literature is directed towards its occurrence.

In 1970, Sepp (33) reviewed the literature and suggested six sources of nitrate nitrogen pollution; 1) oxidizing deposits of nitrogenous organic matter, 2) mineral fertilizers, 3) liquid wastes, 4) geological deposits, 5) precipitation, and 6) bacterial fixation of atmospheric nitrogen.

Of these, the principal sources of nitrogen (and thus nitrates in surficial ground waters) are fertilizers, wastewater recharge, and oxidization of surface organic deposits such as barnyard waste, feedlot manures, etc. (12, 33).

Once these pollutants enter the soil, they undergo a series of reactions which transforms, degrades, or removes the nitrogen source. The general nature of this nitrogen cycle in the vadose and ground water zones is reasonably well understood (Figure 5) (33). The principal component of this cycle is the nitrification step where ammonia is converted to nitrate in the presence of oxygen. The general equation is given by:

$$NH_3 + 2O_2 \xrightarrow{\text{Bacteria}} NO_3^- + H_2O + H^+$$

In addition to nitrification many other reactions are possible:

1) denitrification of the nitrates into gaseous nitrogen which is lost to the atmosphere (41),

2) adsorption of ammonium ions by negatively charged clay and organic colloids in the soil which can be then oxidized to nitrate by nitrifying bacteria (29),

3) fixation of ammonia by the organic fraction which forms complexes resistant to leaching and decomposition (29),

4) fixation of ammonium ion by being trapped in the inner layers of clay materials where it is quite stable

and resistant to nitrification (20),

5) bacterial incorporation by various microorganisms which tend to fix atmospheric nitrogen (20), and

6) vegetation removal that decreases the nitrogen content (20).

The travel of significant quantities of nitrate nitrogen into the ground water supply can be related to the nitrogen cycle. The nitrification process can produce large amounts of nitrates which are not adsorbed or immobilized in the vadose zone. These nitrates readily leach through the soil into the ground water during periods of infiltration (12, 20). The amount of nitrate nitrogen actually reaching the ground water depends on the magnitude of the source of nitrogen, removal mechanisms, and dilution potential of the system (10, 28).

The nitrogen compounds from point sources (such as septic tank effluents, privies, etc.) are usually high strength slugs that enter the soil system in a small area. This slug being converted primarily to nitrate will travel in horizontal and vertical directions. As shown in Figure 6, where bacterial and chemical soil pollution patterns are presented, the concentration of the load decreases, as the travel distances get larger, due to the removal and dilution mechanisms (32, 35). This fact is important when establishing minimum horizontal

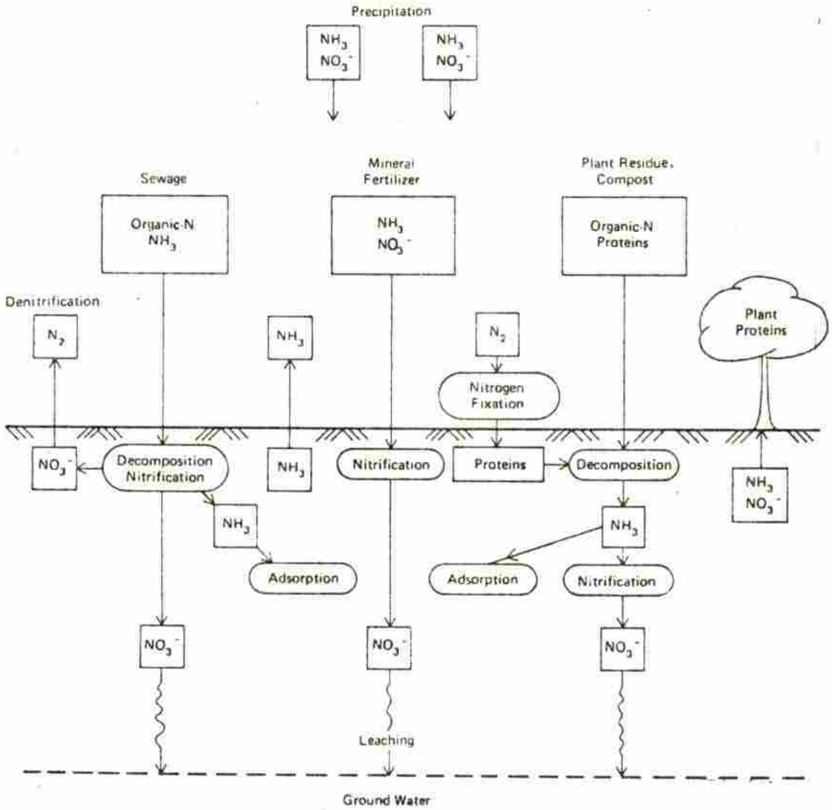


Figure 5. The nitrogen cycle in soil (33)

and vertical protective distances from pollution sources, since the initial nitrogen concentration is significantly reduced.

Non-point pollution sources (including fertilizers in farmlands, pasture land, and barnyards) represent another major source of nitrogen into the soil system. For example, seasonal rainfall increases the nitrogen load entering ground water supplies by leaching nitrate from fertilized fields. Gillham and Webber (12) suggest that this amount is usually small, but the excess load enters the surficial aquifer as slugs with little mixing and dilution with the native ground water. For this reason, fairly small quantities of pollution percolating through the soil may enter a well as a high-concentration slug long after its initial entry into the aquifer (41).

In addition to the leaching of nitrates through the soil matrix, nitrogen contamination could occur as a result of the by-passing of the natural soil system. For example, ground water pollution is likely to be more extensive in areas underlain by course-grained material, fractured bedrock, or limestone with extensive solution channels (20, 21). Sink holes in many parts of Iowa provide easy access for pollutants to enter cavernous limestone formations. Then the pollutant may travel great distances to plague a well water supply.

BACTERIAL AND CHEMICAL SOIL-POLLUTION PATTERNS AND MAXIMUM MIGRATIONS

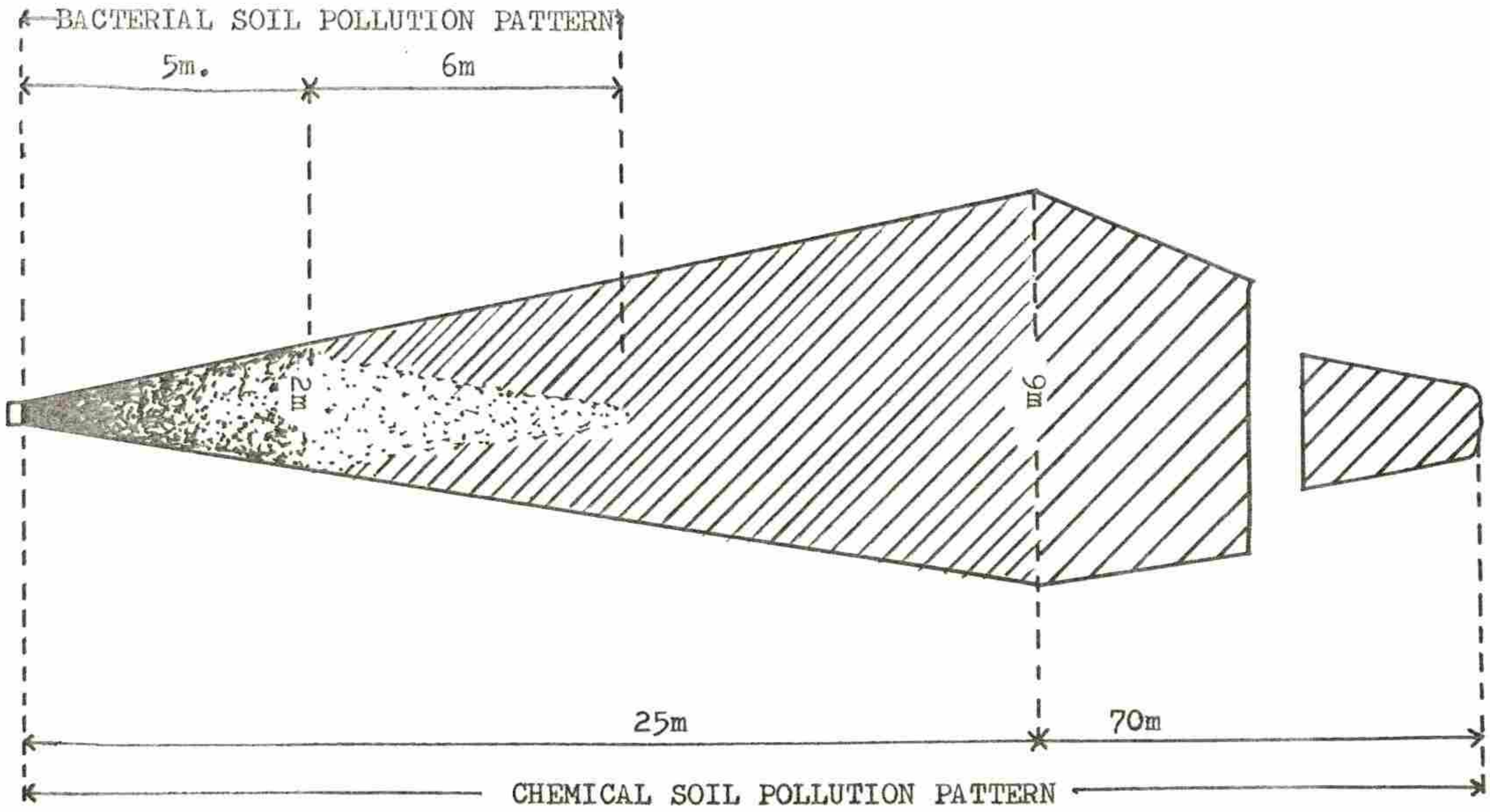


Figure 6. Ground water mal-enclave from point source penetrating water table in fine, sandy soil (15).

## Well Construction

A great deal of ground water pollution results from subsurface excavations, including water wells, that allow pollutants to enter an aquifer directly (9). Any time a hole or excavation is constructed which provides a possible avenue to by-pass the surface filtering systems, the chance of pollution is greatly increased. These subsurface excavations may be grouped into one of several categories: water wells, sanitary facilities, underground mines and tunnels, construction excavations, quarries, strip mines, burial vaults, injection wells, and land fills. It is difficult to determine the extent at which these sources are polluted. For example, the best known occurrence of ground water pollution from planned waste-disposal activities is from waste pits or lagoons containing organic wastes (40). Other examples of contamination include the waste injection wells which inject pollutants into subsurface reservoirs (9). However, excessive injection rates, fractured bedrock, casing failure, or many other possible failures may permit these waters to enter a fresh water aquifer (1). These examples and many others illustrate the need for criteria as related to subsurface excavations, be developed to manage the quality of ground water.

Basically, a water well is constructed be excavating a hole in the earth's crust and lining the opening with an appropriate material so that the hole will not collapse. The well is then made operative by placing a pump inside the lining which lifts the water to the surface of the ground. There are five principal classifications of water wells: dug, bored (augered), driven, drilled, and jetted (4). Dug wells are excavated with hand tools or with bucket type mechanical equipment. These large diameter wells are seldom constructed to any appreciable depth. Bored wells are constructed with a power-driven rotating auger. This type is often used where small quantities of water are desired at relatively shallow depths. These two types of wells are most susceptible to contaminants since the brick or tile walls are generally not water-proof and lack proper sanitary seals to exclude surface drainage (14).

A drilled well is one equipped with both a casing and a drop pipe. There are two methods of drilling wells, the rotary method based on the rotation of the cutting tool, or the cable tool method using a percussion or crushing motion by the drilling bit. The advantages of drilled wells include a great depth range to obtain potable water, water tight joints, and good protection from surface drainage when a pitless adaptor is used. Problem areas lie in the exclusion of contaminated aquifers traveling along the outside of the casing to reach good waters and obtaining good sanitary seals for wells located in pits (4).

The bored and drilled type wells are the most numerous type of construction in Iowa, yet a few driven and jetted wells are encountered. A driven well is constructed by driving a series of pipe sections into water-bearing materials, whereas a jetted well utilizes the erosive action of a jet of water.

A rural Kansas study (30) indicates the most probable numbers (mpn) values of coliform for three types of well construction (Figure 7). As evident from this figure, larger mpn counts existed in dug wells than those observed in drilled and driven wells. This study also indicated that no type of well was found coliform free all year long.

To prevent the impairment of ground water quality by the entrance of foreign material and of contaminated or other undesireable water into well casings, special attention should be given to certain features of water well construction. These factors, both structural and geological, must be recognized, considered, and dealt with to limit pollutant problems. The following features pertain to the health aspect of quality protection (11, 14):

1) Proper well design, including the materials equipment, grouting, and sealing casing, must prohibit contaminants from entering the water supply;

2) disinfection performed so as to remove or destroy any foreign material or organisms that may have been introduced. The effectiveness of this procedure depends on the amount, duration, and type of disinfectant used;

3) the location of a water well must be consistant with the surrounding area and geologic conditions. This includes specific distances from known pollution sources, the location of the well above flood levels or possible submergence, and in accordance to local ground water conditions, porosity, and absorbance of the soil;

4) A minimum protective depth, usually greater than ten feet, to allow water tight sealing and pollution-free water; and

5) abandoned wells are a potential hazard to the water-bearing strata, providing easy access to pollutants entering them.

The location of the well is the first feature to be considered when planning the facility. Authorities agree that water wells should be located a "safe" distance from potential sources of contamination (14). Determination of safe distance involves evaluation of the character and location of the source of potential contamination, permeability of the geologic materials between the ground surface and the water producing aquifer, depth to ground water and its direction of movement, physical character

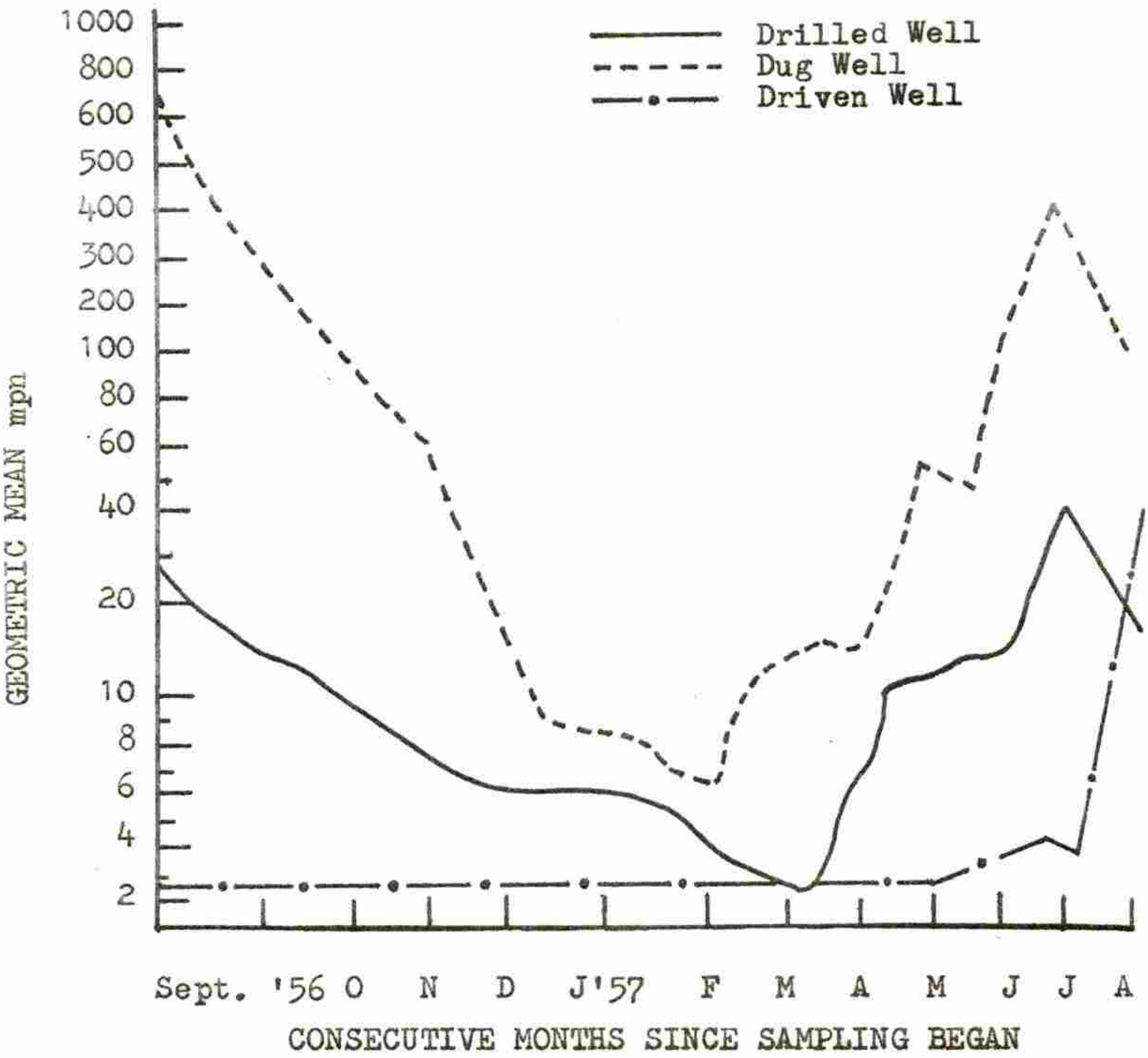


Figure 7. Geometric mean mpn values of coliforms for three types of well construction (30)

of the water-bearing materials, and the effect of well pumping on the direction of ground water movement.

The Iowa Public Health Department (14) has proposed recommendations regarding minimum distances between water wells and various sources of contamination. These recommendations are shown in Table 2.

Whenever possible, wells should derive water from a depth below 20 feet since the upper 10 feet of soil is most subject to contamination (14). There are several openings into well casings which should be sealed or so constructed that surface water and foreign matter are prevented from entering the well. These openings are: 1) the connection between the casing and pump wires, 2) the connection between the discharge pipe and the pump, 3) the holes which provide access to the well, and 4) the annular spacing outside of the well casing (38).

All connections with the surface are usually protected with a sanitary seal. In many cases a gasket or other similar construction practice aid in the exclusion of potential contaminants. Also, the use of grout to fill the annular space and pitless adaptors aids in the protection of the well by sealing off surface waters (4).

A new well, a reconstructed well, or one in which the pump has been repaired is nearly always contaminated from tools, handling of the casing, etc. (13). So disinfection

Table 2. Minimum travel distances recommended for well casing to pollution source (14)

| Source of Contamination | Minimum Lateral Distance |
|---|---|
| Cesspools (receiving raw sewage) | 150 feet |
| Preparation or storage area for spray materials, commercial fertilizers, or chemicals that may result in ground water pollution | 150 feet |
| Soil absorption field, pit privy, or similar disposal unit | 100 feet |
| Poorly drained barnyards, accumulations of manure | 100 feet[a] |
| Septic tank, concrete vault privy, sewer of tightly joined tile or equivalent material, sewer connected foundation drain | 50 feet |
| Well-drained barnyards, animal pens or stalls having concrete floors or silos | 50 feet[a] |
| Sewer of cast iron leaded or mechanical joints, indipendent clear water drains, or cisterns | 10 feet |
| Cast iron sewer with leaded joints encased in 6 inches of concrete | 5 feet |
| Pumphouse floor drain, cast iron with leaded joints, draining to ground surface | 2 feet |

[a]Downslope from well.

of new or repaired wells is always recommended to protect the water users. A chlorine solution of sufficient strength is placed in contact with all contaminated surfaces long enough for complete destruction of all disease-producing organisms. The adequacy of disinfection should be checked by a subsequent bacterial examination.

Wells taken out of service are a hazard to the water-bearing strata by providing easy access for pollution to enter the formations supplying water. These "abandoned" wells should be adequately capped, plugged, or filled so as to reduce this potential danger. The degree to which state agencies understand the potential impact of abandoned wells on ground water quality is reflected in their well regulations. Nine states (including Iowa) claim that their states have no problems with abandoned wells, and therefore have no regulations to deal with them (37). Numerous documented case histories have indicated that abandoned wells can be of public health significance.

# PROCEDURAL APPROACH

The effects of well construction on the quality of water from rural well water systems was studied taking into account the variable nature of ground water. The determination of the magnitude of well water pollution in Iowa involved the use of previous well testing programs and surveys and the review of several case histories from the files of the Iowa State Department of Health (ISDH). Through the county agricultural extension service, the results of many of these countywide well water quality surveys were obtained for several Iowa counties.

Several shallow augered or drilled wells, which had shown significant well construction defects or a history of contamination, were identified for a water quality sampling program. Case histories or letters from angry well owners reported to the ISDH and county wide sampling surveys taken by the county sanitarians provided useful information for the selection of the sampling sites.

Once the location of a large number of these problem wells was obtained, a field inspection and sampling survey helped to determine several suitable wells for further study. This enabled a few select problem wells to be screened out and used for continued research purposes.

The site survey involved the determination of well type and depth, location of all potential pollution sources near the well, evaluation of sanitary protection measures, well construction histories, and a personal interview with the well owner. A sampling program was developed to collect water samples from each well at weekly or biweekly intervals for a 9 month time period. Analysis of total coliform and fecal streptococci bacteria and nitrite + nitrate nitrogen was conducted on each well water sample.

The total coliform and fecal streptococci test results were done by the Veterinary Diagnostic Laboratory of Iowa State University using the membrane filter technique as outlined in Standard Methods for Examination of Water and Wastewaters (34). The nitrite + nitrate nitrogen samples were submitted to the Analytical Services Laboratory of the Energy Research Institute, using the automated, nitrogen (nitrite and nitrate) cadmium reduction method as shown in Standard Methods for Examination of Water and Wastewater.

The actual well testing program included the extensive sampling (either weekly or biweekly sampling) of seven wells, numbered 1-7, located in Poweshiek County, Iowa. These wells were surveyed over the period of August 21, 1978 through May 17, 1979, to look at the effects of seasonal variation. The sampling procedure used for the various testing parameters (Appendix A) had to be flexible enough to account for the variable nature of the well waters, yet also obtain a representative sample.

Wells 1 and 5 were shock chlorinated in order to observe the rate of increase in total coliform and fecal streptococci following disinfection. The shock chlorination was done using the procedure listed in Appendix B. The two bacteria test parameters were taken before and after the chlorination to determine the extent of microbial kill.

In May, 1979, several other wells in Polk and Dallas Counties, Iowa, were sampled for water quality. These wells (numbered 8-14) have no major construction defects, and were sampled to show their response to environmental changes. Information obtained from the well driller provided much insight into the well construction problems throughout Iowa.

# RESULTS AND DISCUSSION

A good well is known by the good water of reasonably uniform quality that it produces. Throughout Iowa, ground water occurs under diverse conditions and in a variety of sand and gravel or rock types. Also, the occurrence, movement, and behavior of both natural and man-made contaminants makes it difficult to achieve good water quality at all times at all locations.

## Statewide Well Water Conditions

In Iowa, several of the water quality problems associated with rural well waters have been discussed by other researchers. Surveys or testing programs have been performed in several Iowa counties to sample a large number of wells. Various groups such as 4-H clubs, agricultural extention agents, county sanitarians, and boys clubs conducted testing programs that gave much information on the magnitude of well water contamination. Although the sampling programs of many of these surveys were not totally random, they do give a good indication of the pollution problem in their county area.

Table 3 shows the results from 10 countywide surveys involving about 2,400 rural wells. For these 10 counties, the results show that a large number of the wells sampled exceed either the recommended bacteria or nitrate standards

Table 3. Summary of sampling surveys or testing programs taken in Iowa counties by various groups

| County | Testing Year | Results of Coliform Bact. Tests | | Results of Nitrate Tests | |
|---|---|---|---|---|---|
| | | Meets Stds.[a] | Exceeds Std. | Meets Stds.[b] | Exceeds Std. |
| Sioux | 1968-69 | 157 | 252 | 193 | 138 |
| Ida | 1977 | 32 | 125 | 147 | 39 |
| Plymouth | 1977 | 56 | 33 | 85 | 19 |
| Floyd | 1970 | 127 | 124 | 190 | 61 |
| Chickasaw | 1970 | 155 | 20 | 137 | 38 |
| Calhoun | 1976 | 82 | 48 | 119 | 11 |
| Mitchell | 1969 | 281 | 153 | 338 | 96 |
| Humboldt | 1952-59 | 250 | 197 | N.A.[c] | N.A. |
| Union | 1970 | 24 | 65 | 26 | 32 |
| Hardin | 1971 | 169 | 40 | 117 | 9 |
| | | 1333/2400 | 1067/2400 | 1235/1637 | 402/1637 |
| | | 56% | 44% | 75% | 25% |

[a] No. of samples less than 1 coliform per 100 ml.

[b] No. of samples with nitrate less than 10 mg/1 as N.

[c] Not available.

or both. The total coliform test revealed that about 44% were greater than the Environmental Protection Agency (E.P.A.) standards of 0 colonies per 100 ml. Also the nitrate test, with an E.P.A. standard of 10 mg/l as N, was exceeded in about 25% of the samples taken. Even though the results of these surveys are somewhat limited in scope, the extent of the well water pollution problem in Iowa is evident.

The counties located in the limestone areas of northeast Iowa generally are below average in the bacteria tests. Table 3 shows that Chickasaw, Mitchell, and Hardin Counties have coliform bacteria results well below the 44% failure rate. Most of the wells in these counties are drilling wells into the limestone bedrock.

In Sioux, Ida, and Union Counties most wells obtain water primarily from surficial sand and gravel aquifers, or sand and gravel deposits within the glacial till. These counties show a higher than average bacteria count. Most of the wells constructed in these areas are of the augered or dug type. The type of well construction has been related to the occurrence of well water pollution. Information and data obtained from some of the county surveys give good indication of this relationship. Table 4 indicates a summary of Plymouth and Ida Counties surveyed for coliform and nitrate levels. The important aspect of these results is that dug and augered type wells seem to have a larger number of wells with both high bacteria and high nitrate levels.

Table 4. Summary of two Iowa counties testing programs showing water quality as relating to type of well construction (Data in Table C4)

| Type of Well | Percent exceeding Bacteria Standards[a] | Percent exceeding Nitrate Standards[b] |
|---|---|---|
| Dug | 90% | 19% |
| Augered | 77% | 33% |
| Drilled | 36% | 28% |
| Driven | 17% | 3% |

[a]EPA standards are 0 coliform bacteria colonies per 100 ml.
[b]EPA standards are less than 10 mg/l nitrate as N.

## Experimental Analysis

Through the assistance of the Poweshiek County Sanitarian, 7 wells were located for a long term sampling program. These wells (numbered 1-7) have had a history of contamination and were available for routine sampling. The purpose of this sampling program was to study the nature of pollutants that plague well waters, to determine the causes or reasons behind them, and to observe the variations in water quality in wells over a long period.

The initial sampling of the 7 wells included an extensive site survey and information gathering in addition to testing for indicator pollutants. The information obtained from this survey is presented in Table 5. Each well was listed according to its construction type. The augered wells, with or without grout, and the drilled wells were then summarized to portray their depth, chief construction defect, and location relative to pollution sources. This summary is important when determining the cause of pollution in the well and then describing the fluctuations of the indicator test data. As can be seen, the major construction defects in Wells 1-7 included the lack of sanitary protection and seal, no grouting technique, or location within 100 feet of human or animal pollution.

The test results for Wells 1-7 are illustrated in Figures 8 through 21. The numeric data are listed in Appendix C. Toward the end of the testing survey 7 additional wells (numbered 8-14) were sampled to determine their water quality. These wells which were grouted to 10 feet exhibit no visible construction defects or potential contamination sources nearby. All 14 wells help to portray the relationship between the physical aspects of the well to the degree of pollution encountered.

A large number of rural farm wells are of the augered

Table 5. A description of the 14 wells sampled listing certain physical characteristics

| Well Number | Depth (ft.) | Chief Construction Defect | Pollution Source within 100 feet: animal | Pollution Source within 100 feet: human |
|---|---|---|---|---|
| Augered Wells | | | | |
| 1 | 48 | casing not sealed at top | yes | yes |
| 2 | 22 | near abandoned well | no | yes |
| 3 | 20 | casing not sealed at top | yes | yes |
| 4 | 20 | casing not sealed at top | yes | no |
| 5 | 38 | casing leakage | yes | no |
| Augered Wells Grouted to 10' | | | | |
| 8 | 56 | none noted | no | no |
| 9 | 60 | none noted | no | no |
| 10 | 60 | none noted | no | no |
| 11 | 60 | none noted | no | no |
| 12 | 110 | none noted | no | no |
| 13 | 67 | none noted | no | no |
| 14 | 100 | none noted | no | no |
| Drilled Wells | | | | |
| 6 | 50 | pit, poor sanitary seal | yes | no |
| 7 | N.A.[a] | none noted | yes | no |

[a] Not available.

or drilled type of construction. Potentially serious consequences might develop in the future with the large number of these available pollutant sources. These wells usually show defects in sanitary protection and seal to surface contaminants, location to pollution sources, improper construction, well completion steps, or maintenence. For example, Well 1 allows runoff from a nearby feedlot to enter the well through cracks in the casing. Likewise, Wells 2 through 6 show important defects such as poor sanitary seals, leaky well pits, and poor location, which can effect water quality.

In Iowa, seasonal changes produce variations in the sanitary quality of well water. Several rural wells (numbered 1-7) were sampled for total coliform, fecal streptococci, and nitrite + nitrate nitrogen levels over a 9 month period. The sampling survey included weekly testing of the wells in the fall and spring months and biweekly testing through the winter months. Large fluctuations in the bacteria counts were observed in most wells though there was much less variation in nitrogen levels.

The total coliform and fecal streptococci bacteria levels for Wells 1-6, follow similar trends. In the fall and spring months, large fluctuations in the bacterial data are shown very well by Figures 8-14. Whereas the winter months show significant dampening of these peaks and reduction of the colonies present.

The nitrite + nitrate nitrogen results over the nine month period show only minor fluctuations due to seasonal changes. For example, Well 1 (Figures 8 and 15) shows similar cyclic trends for both bacteria and nitrogen amounts, but the degree of fluctuation is much smaller for the nitrate.

From the review of literature the possible causes of these trends are: 1) sampling error, 2) a contaminated aquifer, or 3) an inflow of surface contaminants. In Well 1, as in most of the others, the principal cause of pollution is thought to be surface drainage entering the well water after periods of rainfall. The rapid rise and fall of bacteria data indicates a slug of pollutants has entered the well. Well 1 shows a rapid response after periods of rainfall. Jones (16) has shown that coliform bacteria and other indicator organisms survival in ground water is normally less than three weeks. This would suggest that the observed high bacterial counts in Well 1 are of recent origin and are probably due to a frequent inflow of bacteria from surface sources, since the soil removal mechanisms effectively removes bacteria after a few feet of travel. The nitrate level in Well 1, which remains rather constant, suggests that only a small input of polluted water has entered the well. This fact coupled

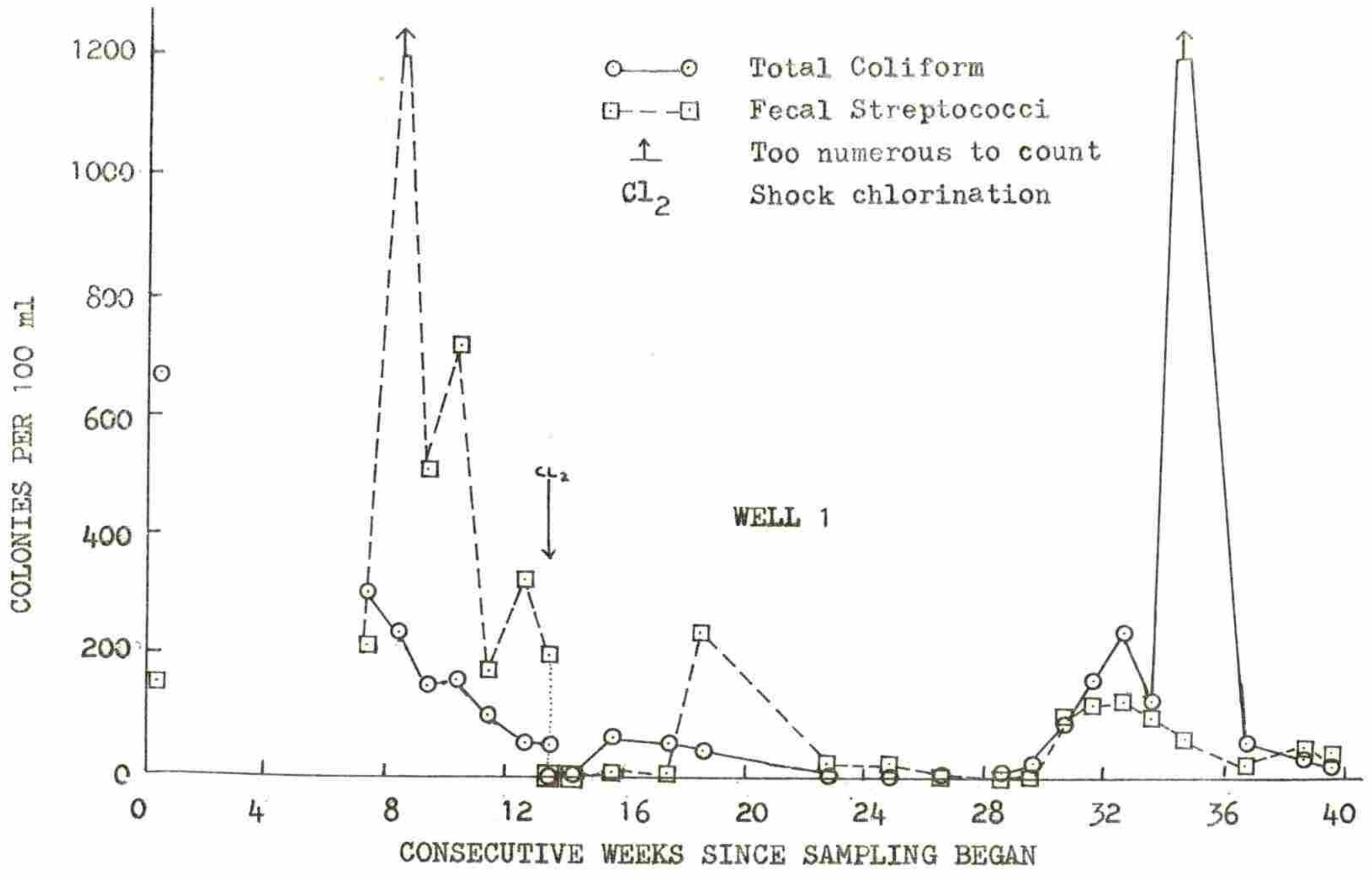


Figure 8. A presentation of the total coliform and fecal streptococci results for Well 1 for the period of August 21, 1978 through May 17, 1979 (data in Tables C1 and C2)

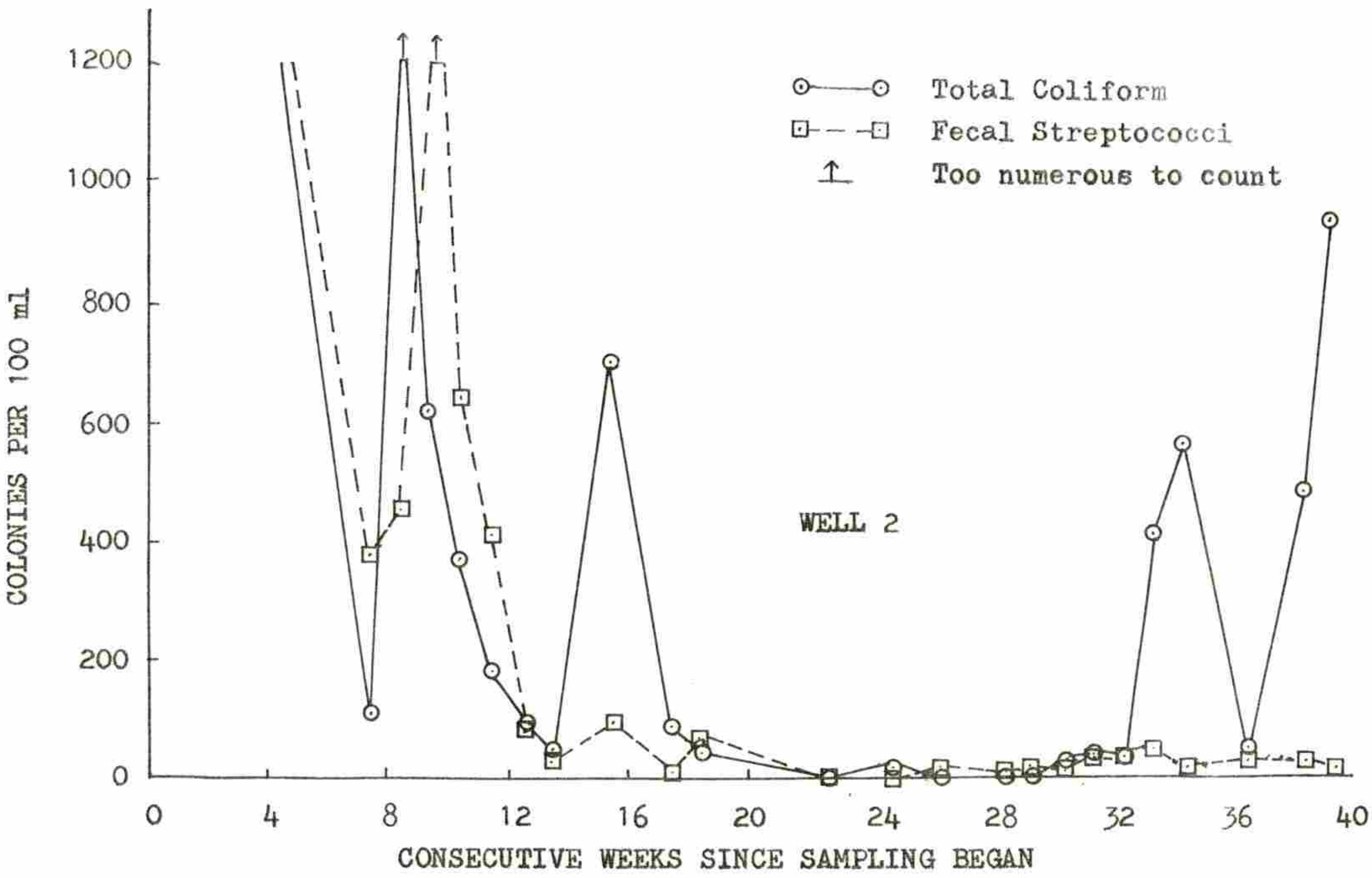


Figure 9. A presentation of the total coliform and fecal streptococci results for Well 2 for the period of August 21, 1978 through May 17, 1979 (data in Table C1 and C2)

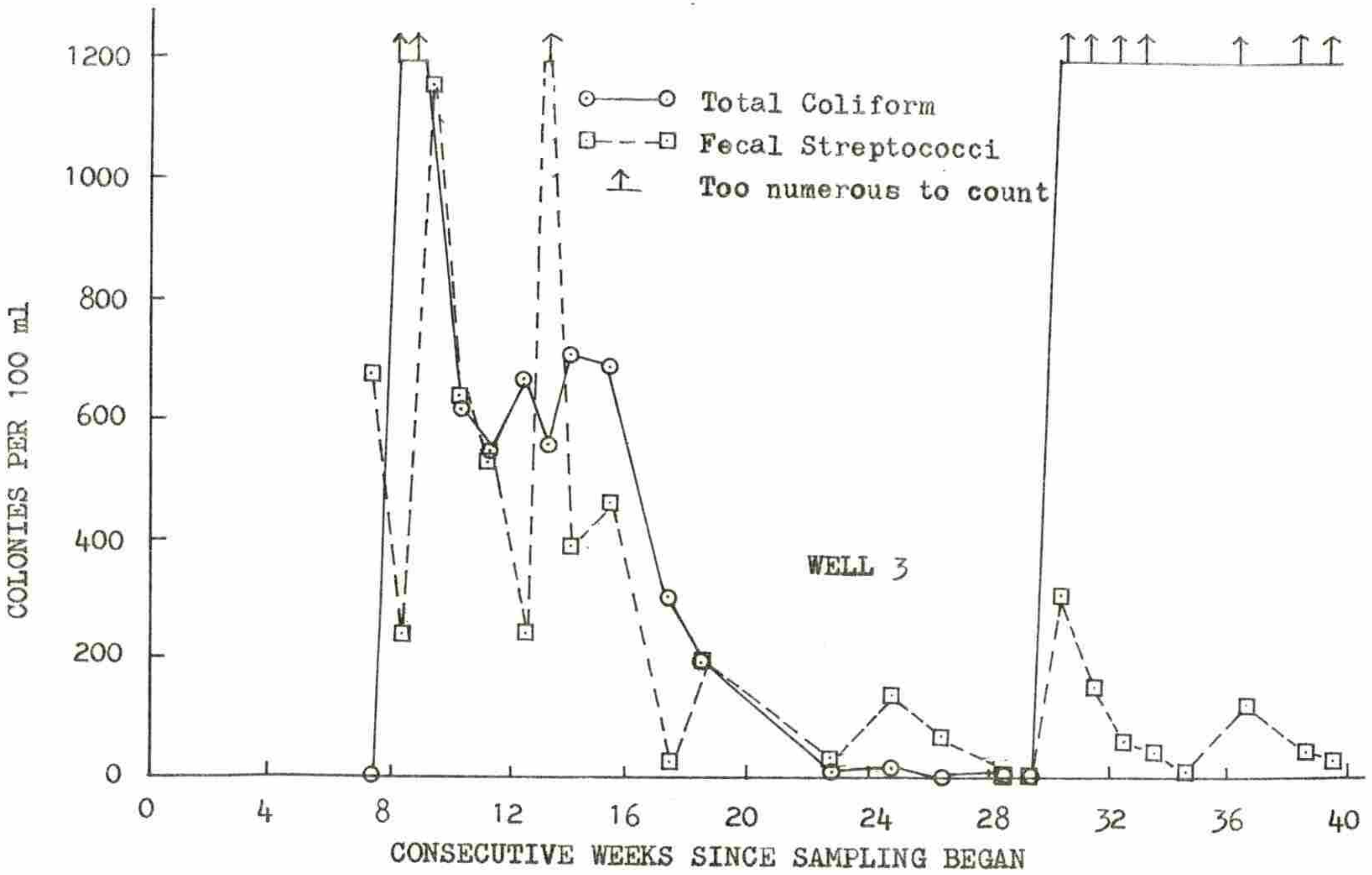


Figure 10. A presentation of the total coliform and fecal streptococci results for Well 3 for the period of August 21, 1978 through May 17, 1979 (data in Tables C1 and C2)

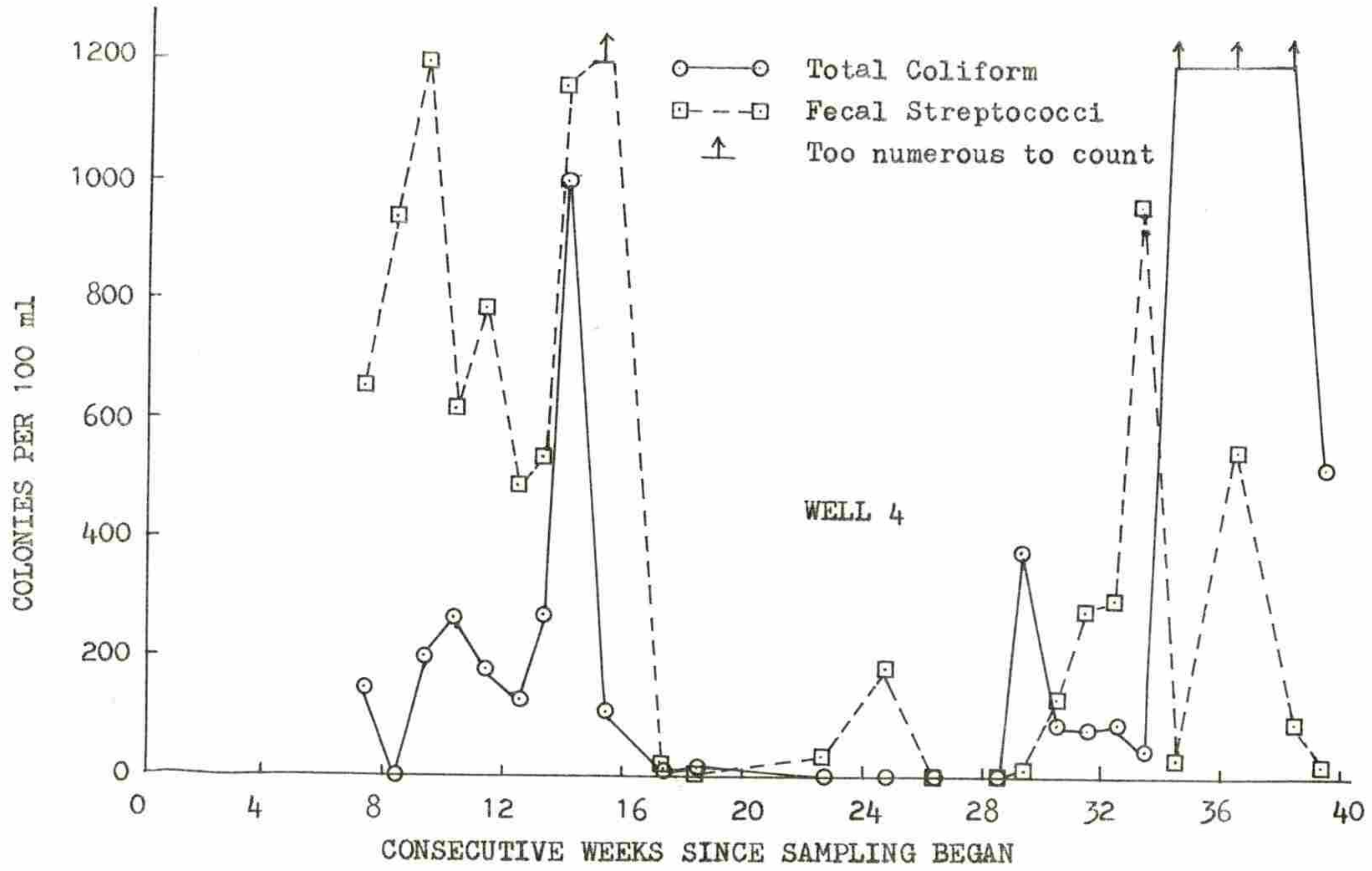


Figure 11. A presentation of the total coliform and fecal streptococci results for Well 4 for the period of August 21, 1978 through May 17, 1979 (data in Tables in C1 and C2)

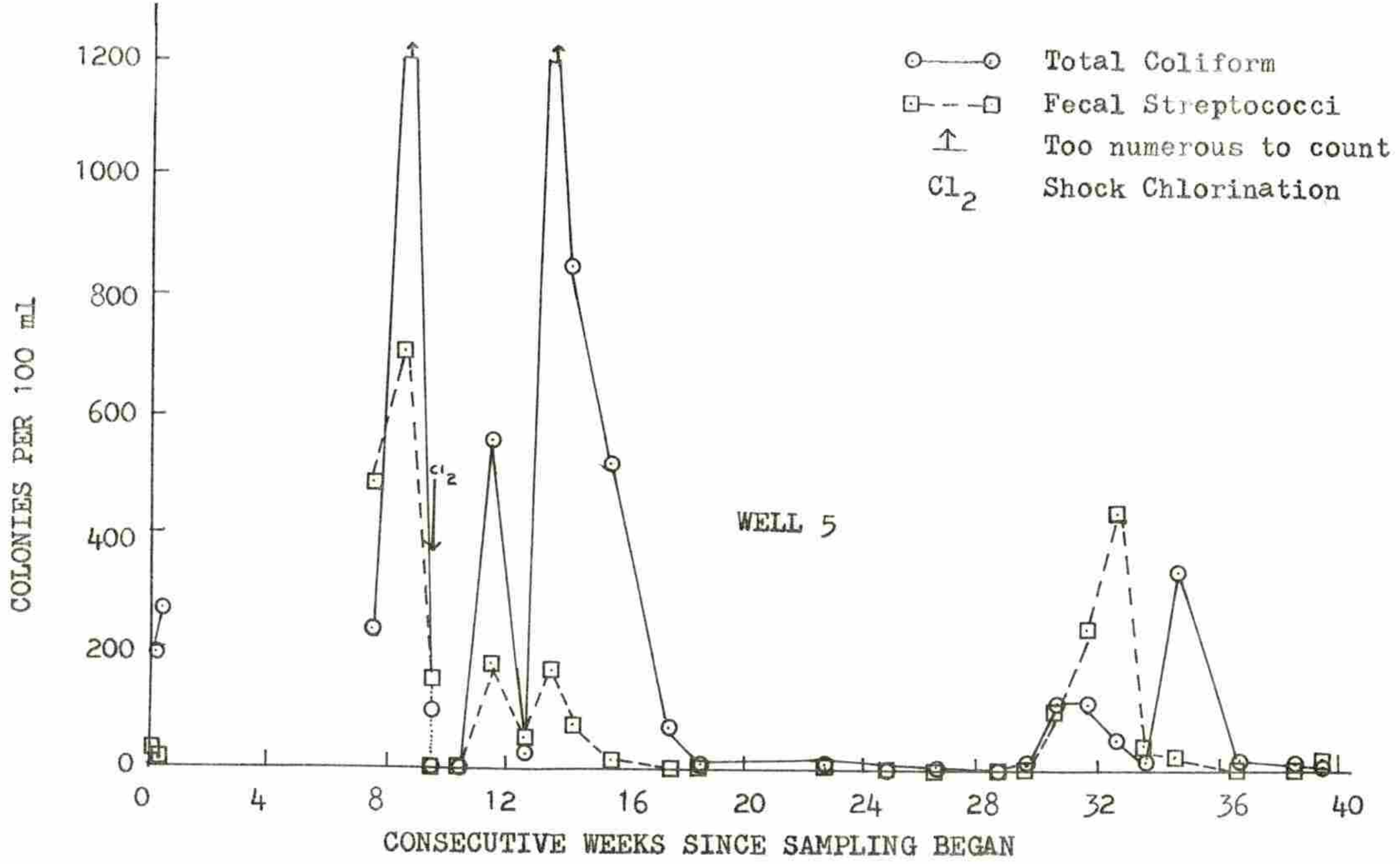


Figure 12. A presentation of the total coliform and fecal streptococci results for Well 5 for the period of August 21, 1978 through May 17, 1979 (data in Tables C1 and C2)

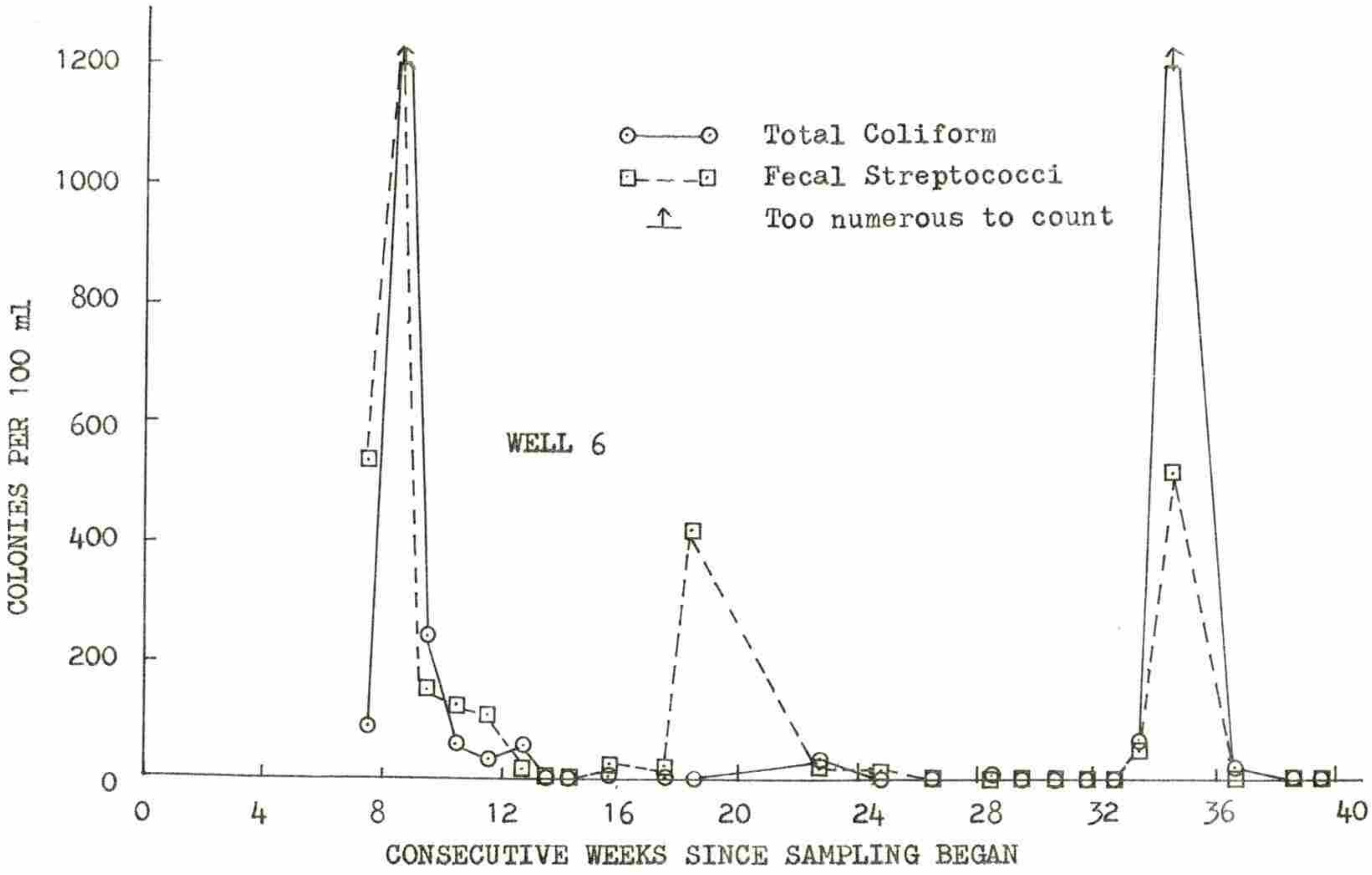


Figure 13. A presentation of the total coliform and fecal streptococci results for Well 6 for the period of August 21, 1978 through May 17, 1979 (data in Tables C1 and C2)

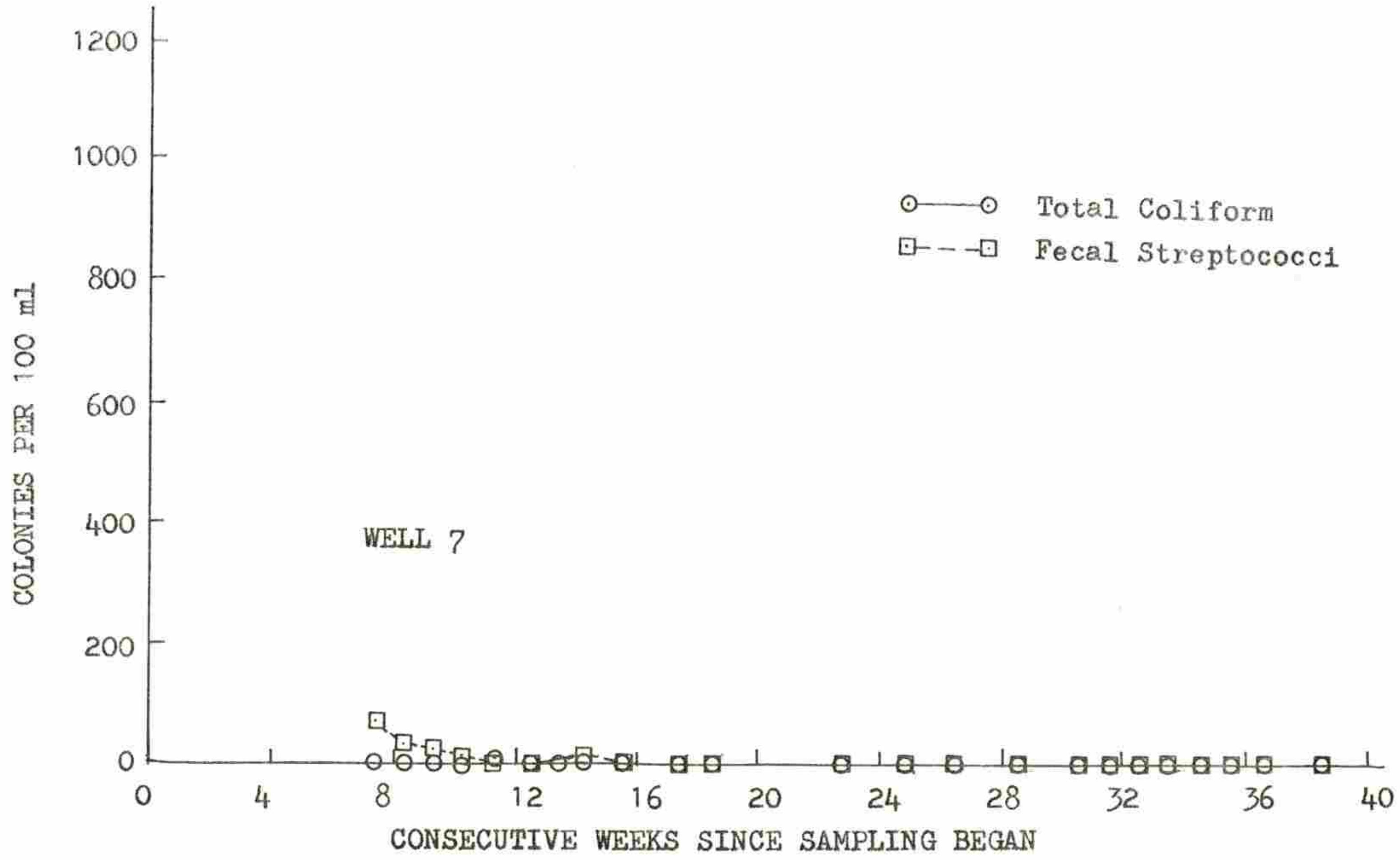


Figure 14. A presentation of the total coliform and fecal streptococci results for Well 7 for the period of August 21, 1978 through May 17, 1979 (data in Tables C1 and C2)

with the high bacteria levels shows that contaminated water in this well came from a small amount of surface inflow and not through the ground water aquifer.

Well 5 which shows high bacteria and high nitrate levels (Figures 12 and 19) must have a larger amount of surface water entering the well. The well casing contains over seven hundred gallons of water so that a large rise in the nitrate level indicates an amount or concentration of pollutant has entered from a nearby nitrogen source. The transmission path has been determined as being either from surface drainage along the side of the casing, or through a channel in the ground water aquifer.

In considering the findings about this group of wells, apparently it is difficult to obtain samples from a well that shows constant levels of water quality all year. There is no such thing as a uniformly contaminated well, that is, one that is contaminated the same amount at all times. In the matter of number and timing samples, it is obvious from Figures 8-13 that one random sample may tell very little about the true quality of well water. To obtain a true indication of the quality of ground water where the well is located, a number of samples must be taken from the well in a timely manner.

The effects of precipitation on the bacterial quality of well water is difficult to predict throughout the year.

The correlation of precipitation events with the amount of bacteria present in the well is difficult to establish because of the varying nature of each well, the lag time, and the sampling periods used. Yet as indicated in Figures 8-13 (Wells 1 through 6) during the fall months, the results show that bacterial peaks occur shortly after major rainfall events. These peaks indicate an inflow of bacteria from surface drainage in a short time. This infers there is a direct connection into the well.

The bacterial counts from Well 2 (Figure 9) show good correlation with the precipitation. The large rainfall events which occurred on the 5th, 8th, and 14th weeks of sampling (Figure 22) provided a transmission media for microorganisms to enter this well in a short time. Coliform bacteria counts declined following the high peaks due to a rapid die-off of the organisms present. This decline can be reversed again by another inflow of bacteria from another rainfall event. Similar conclusions can be drawn on some of the other wells.

The colder temperatures in November and December significantly reduces the bacterial survival because of an increasingly hostile environment. This downward trend toward the winter months is shown in the results of every well tested where the bacteria count dipped to 0 colonies per 100 ml at least once during the cold season.

In Well 2, the decline in bacterial counts toward the end of fall (roughly the 16th week) indicates the increasing hostile environment by reducing the magnitude of the peaks. It later reduces the bacterial counts to zero (as indicated in the 23d week). The effect of precipitation, as snowfall, had little effect on the bacteria number in the well compared to the fall months.

As spring approached, the bacteria counts began to rise again as conditions for them became more favorable. But it is difficult to establish trends and relationships between spring precipitation events due to the variable nature of the environment during periods of increasing temperature, soil thawing, snow melt, and precipitation.

The nitrogen cycle is complex in nature, thus making the level of nitrite + nitrate nitrogen in well water difficult to predict with seasonal changes. Since the amounts of the various nitrogen compounds depend largely on the biological populations, seasonal changes might have a significant effect. In Wells 1-3, the nitrate levels recorded show little variation (Figures 15-17) suggesting that seasonal changes have little influence. But in Wells 4-6, (Figures 18-20) there are significant fluctuations throughout the testing period. The drop in nitrate level in Well 6 to almost zero during the winter months (Figure 20) suggests the source of nitrogen has been removed. In

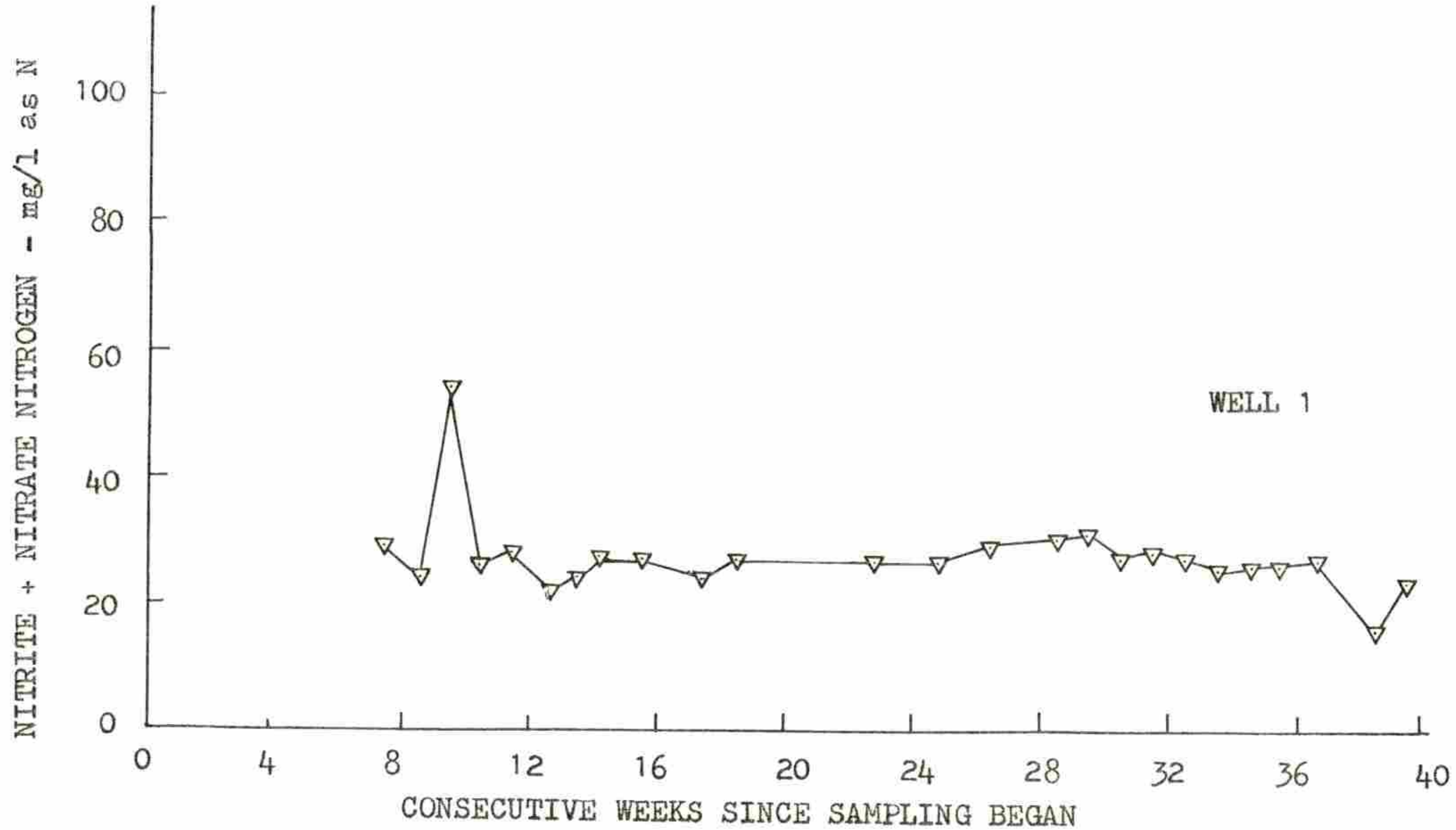


Figure 15. A presentation of the nitrite + nitrate nitrogen results for Well 1 for the period of August 21, 1978 through May 17, 1979 (data in Table C3).

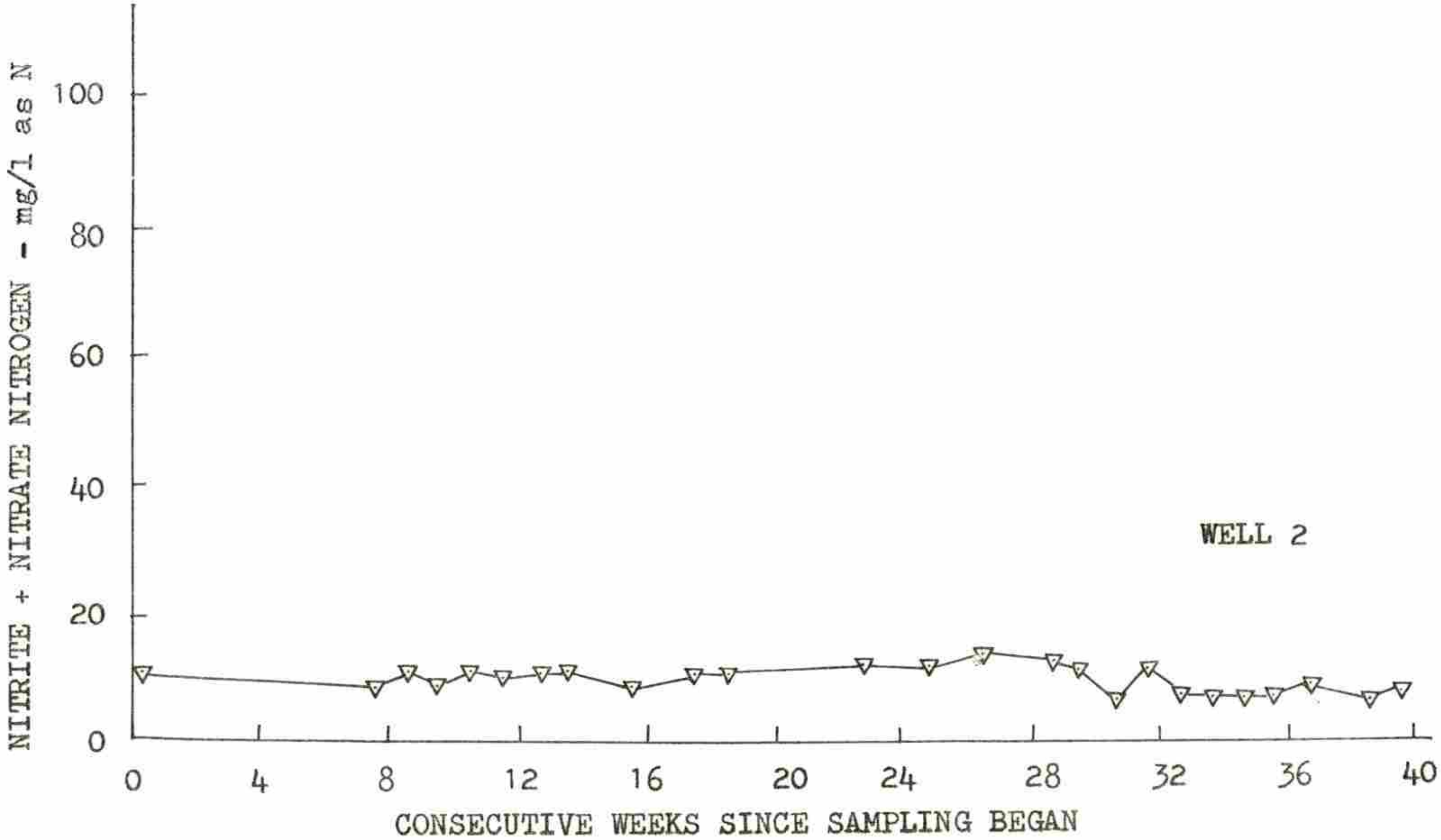


Figure 16. A presentation of the nitrite + nitrate nitrogen results for Well 2 for the period of August 21, 1978 through May 17, 1979 (data in Table C3)

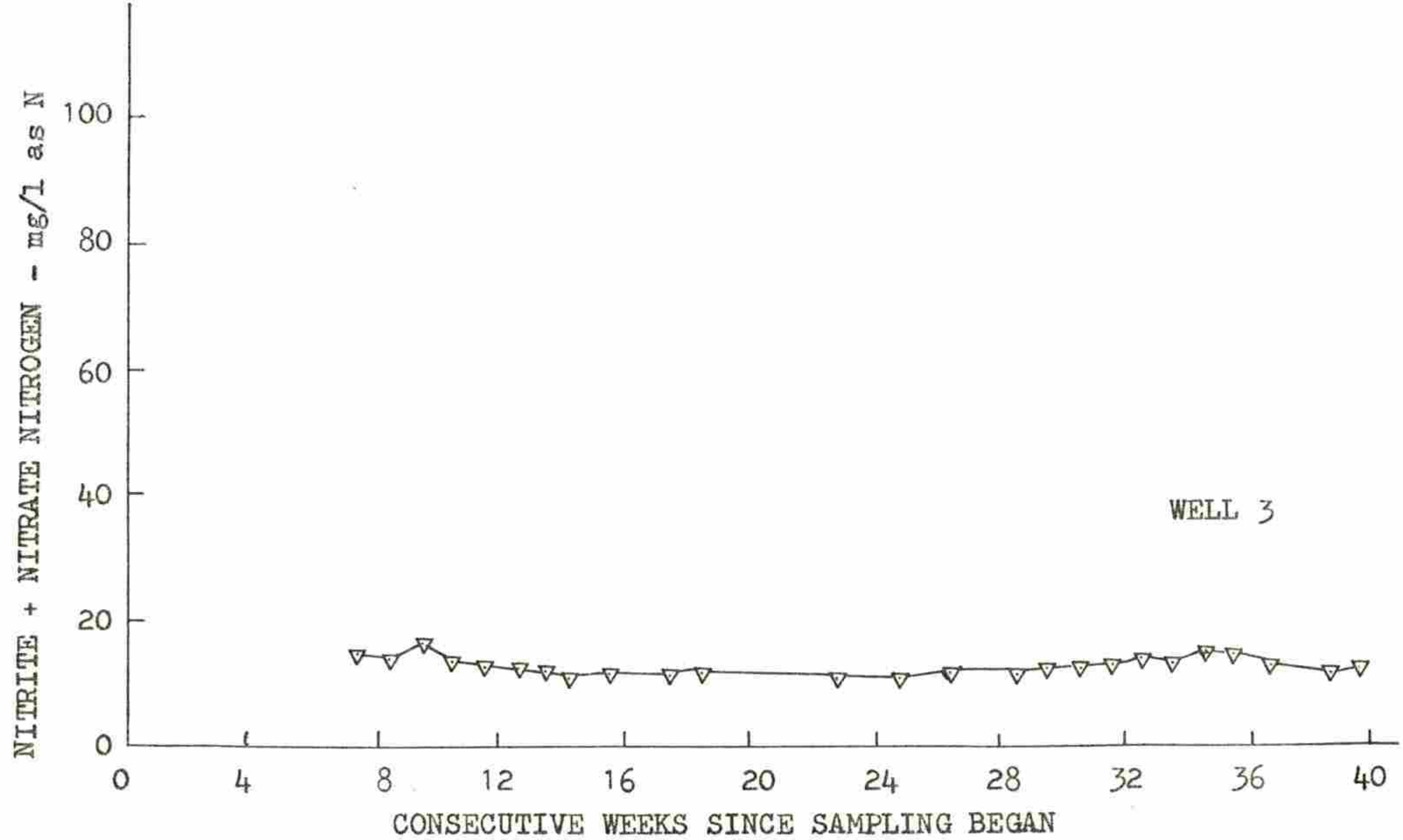


Figure 17. A presentation of the nitrite + nitrate nitrogen results for Well 3 for the period of August 21, 1978 through May 17, 1979 (data in Table C3)

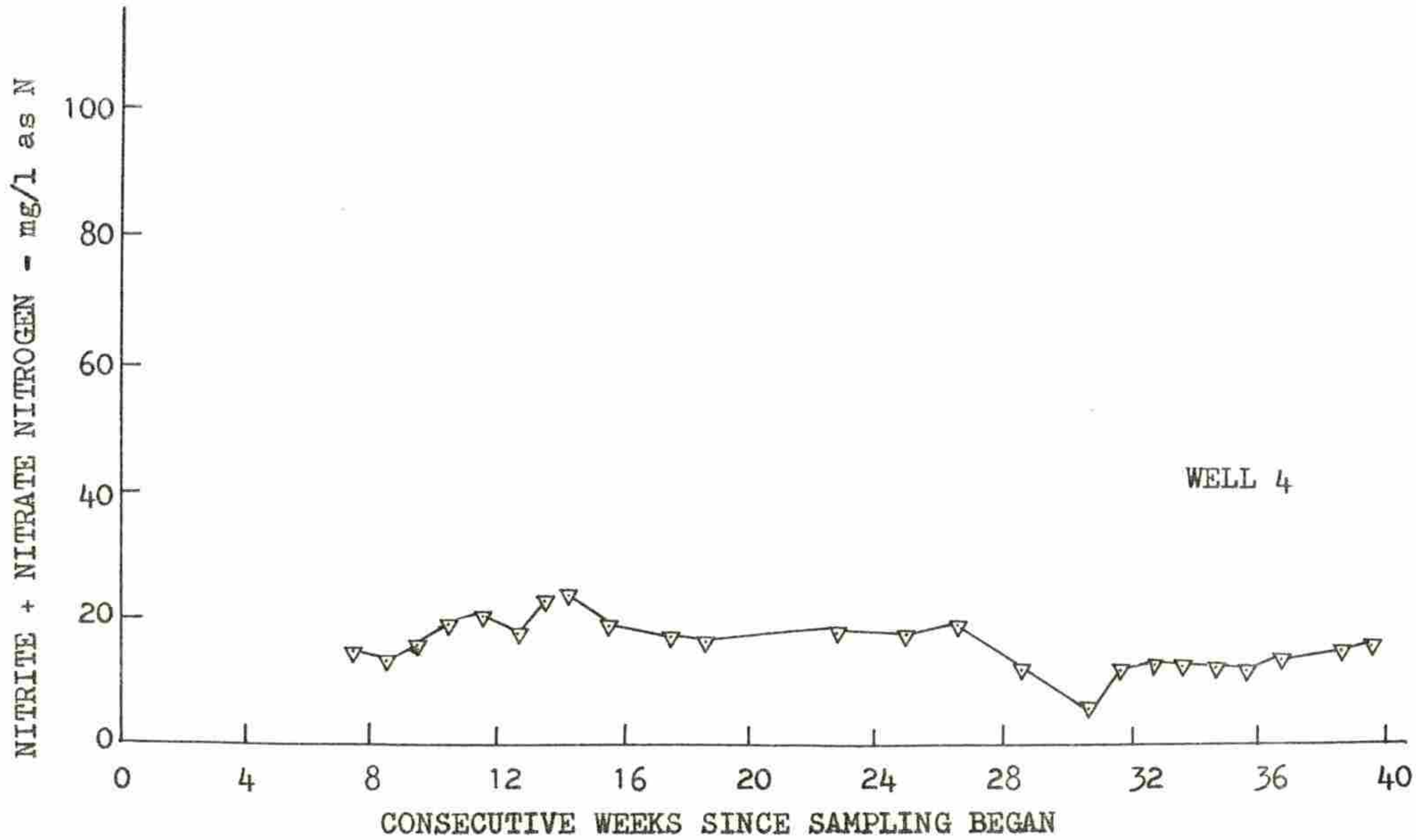


Figure 18. A presentation of the nitrite + nitrate nitrogen results for Well 4 for the period of August 21, 1978 through May 17, 1979 (data in Table C3)

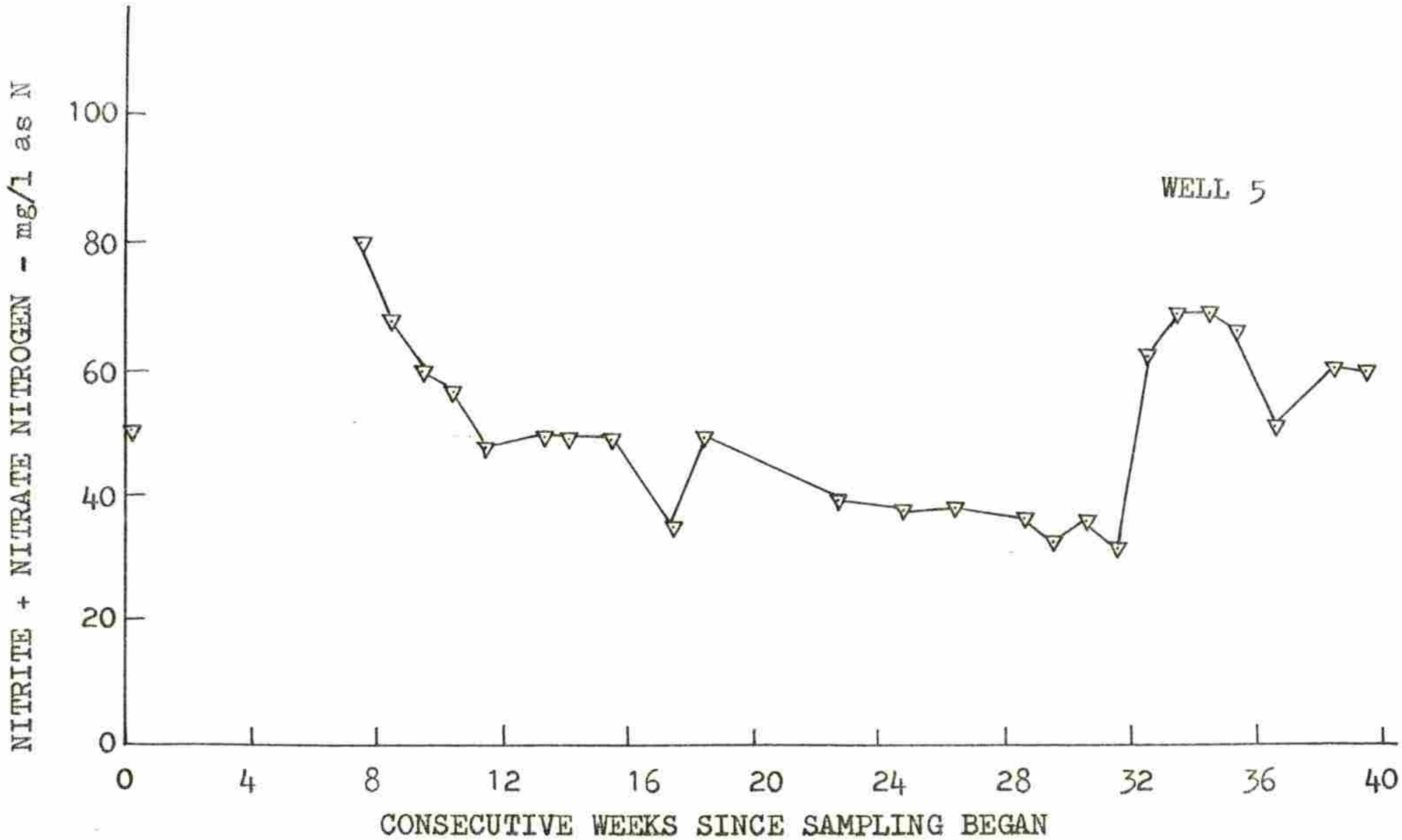


Figure 19. A presentation of the nitrite + nitrate nitrogen results for Well 5 for the period of August 21, 1978 through May 17, 1979 (data in Table C3)

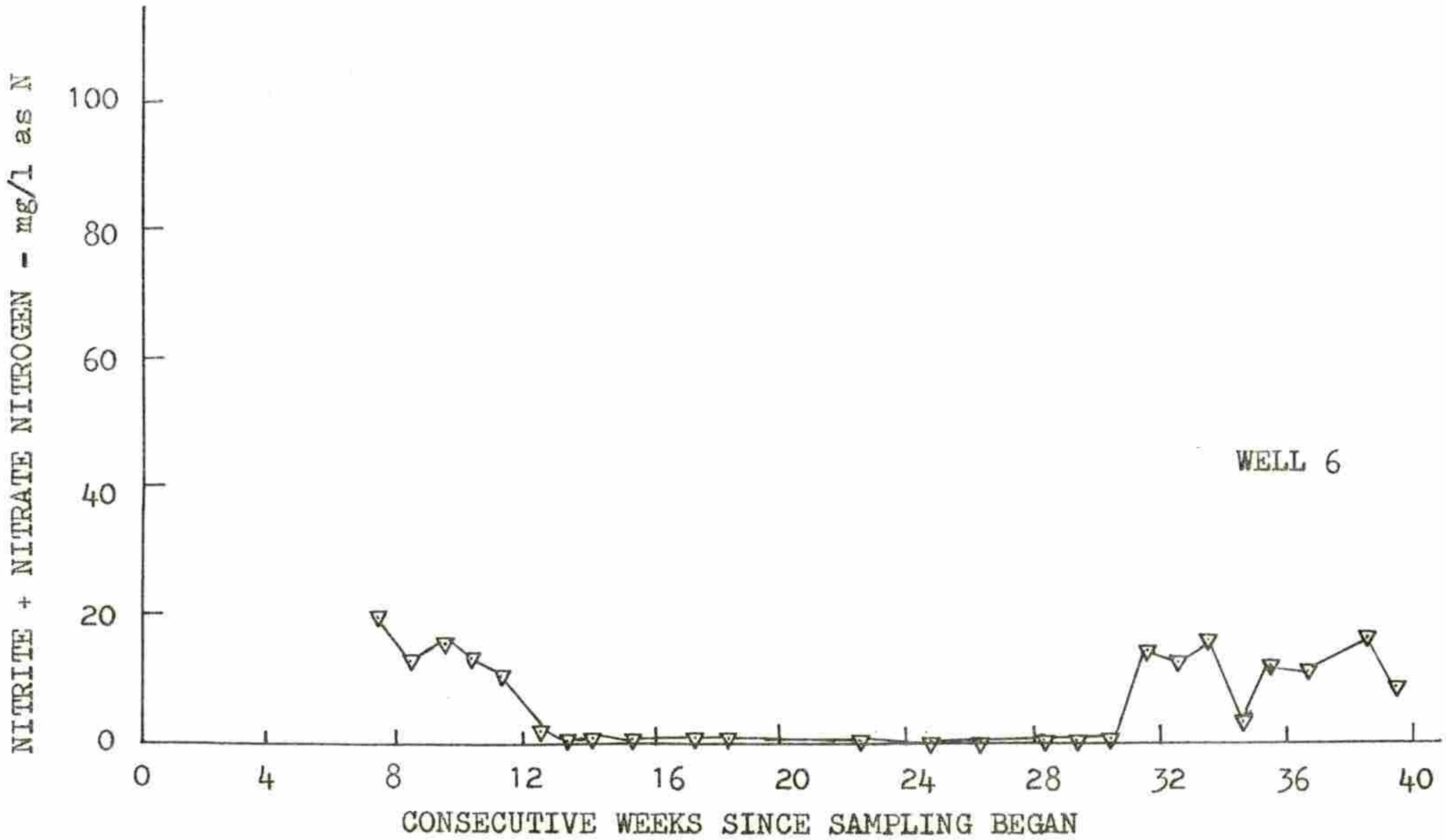


Figure 20. A presentation of the nitrite + nitrate nitrogen results for Well 6 for the period of August 21, 1978 through May 17, 1979 (data in Table C3)

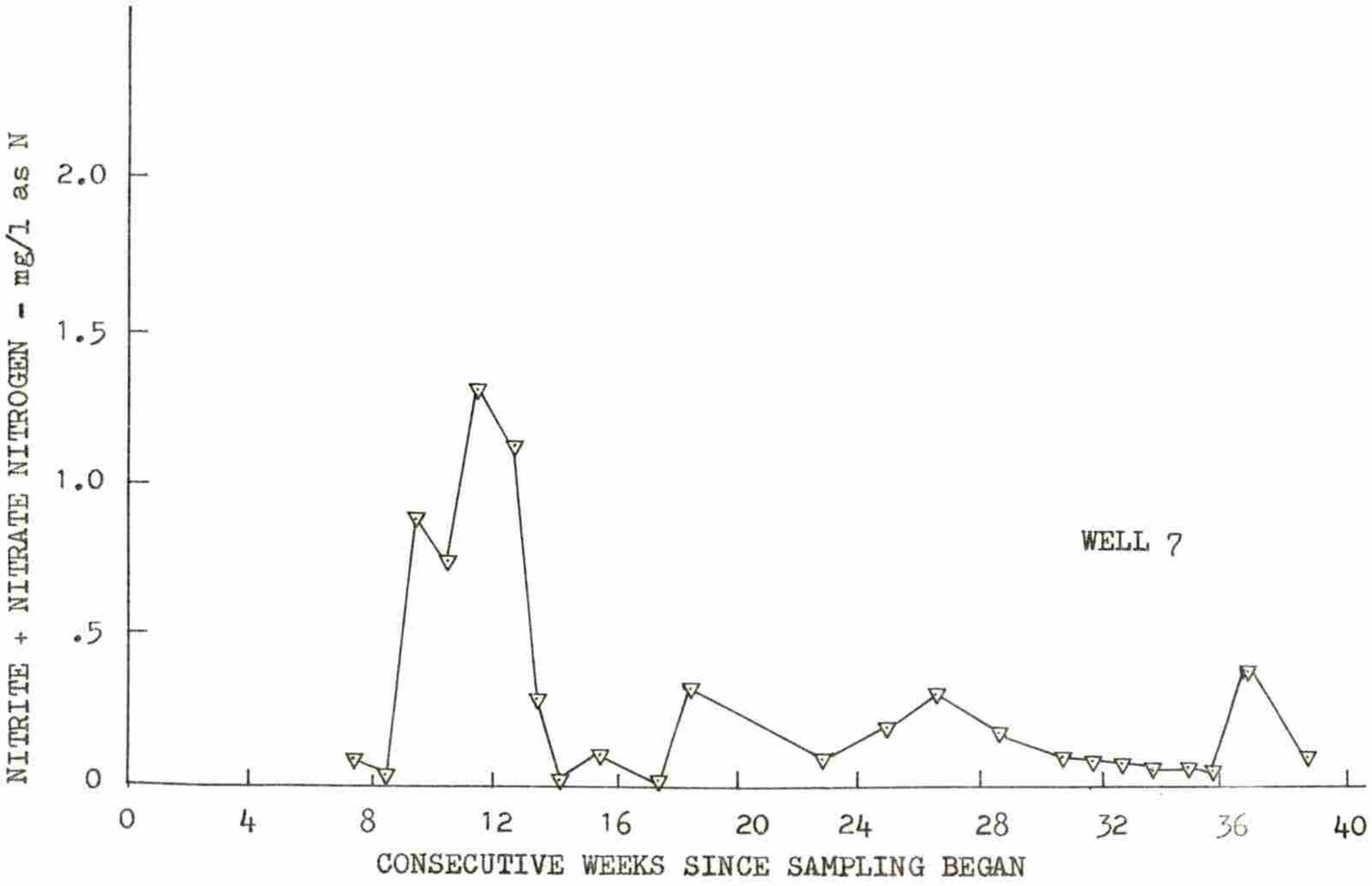


Figure 21. A presentation of the nitrite + nitrate nitrogen results for Well 7 for the period of August 21, 1978 through May 17, 1979 (data in Table C3)

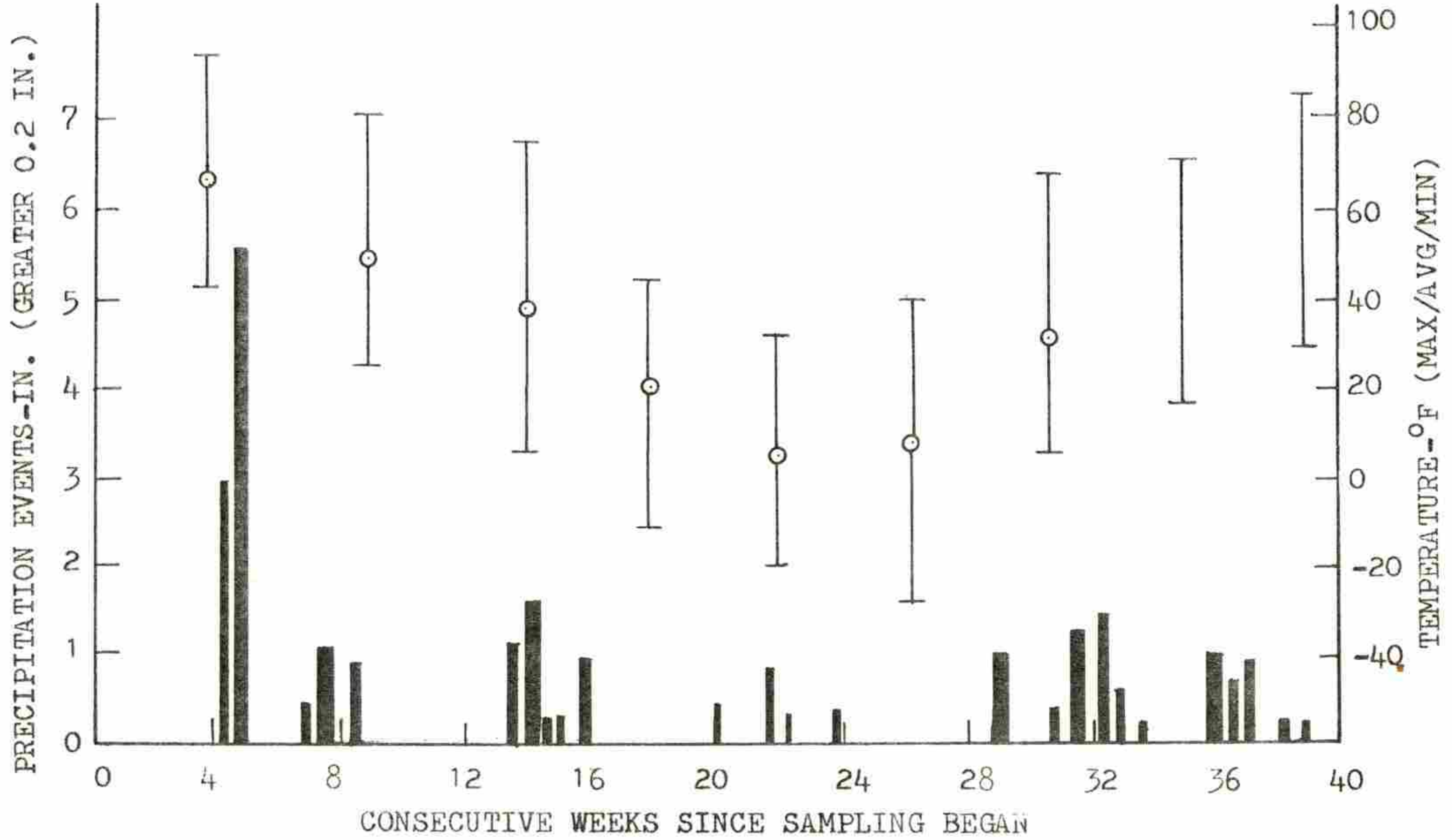


Figure 22. Precipitation events and temperature range for Poweshiek County from August 21, 1978 through May 17, 1979 (36)

this case, the surface runoff entering the well pit would seep through the sanitary seal resulting in high nitrate levels and high bacteria counts. But during the winter months the cold temperatures froze the water in the pit and snow cover inhibited the pollution entry so eventually the nitrate level fell to low numbers. Then as spring approached the nitrate levels again rose, but were difficult to predict. Trends could not be readily established for nitrate levels because the effects of temperature, snow melt, rainfall, and other environmental events occur simultaneously.

An interesting case presenting the vertical movement of nitrate nitrogen in ground water, as researched by Walker (39), is shown by Well 7. The construction of Well 7 is adequate in terms of protection from surface drainage, yet the well is located near a hog feedlot. The movement of nitrogen through the soil as a slug is shown in Figure 21 by an increase in nitrate level (note: enlarged scale) roughly four weeks lag after a period of excess rainfall during the fall months. The effect of colder temperatures makes interpreting the rest of the data inconclusive. But the point emphasized here is that nitrate pollution seepage through soil is a significant problem. There are also many other case histories (35,39,40) where nitrates have contaminated ground water aquifers located too close to pollution sources.

## Test Parameter Limitations

The correlation of disease producing organisms with an indicator test parameter is difficult to establish. The presence of indicator organisms in ground water supplies signifies that potential contamination has occurred. The interpretation by the Health authorities gives guidelines of minimum levels restricting the use of the well. The new U.S. National Drinking Water Standards defines "safe" wells as those which the nitrate concentration levels shall not exceed 10 mg/l as N. Also the coliform bacteria (using membrane filter technique) in samples shall not exceed 1 per 100 ml as the average of all samples examined per month; or, coliform bacteria shall not exceed 4 bacteria per 100 ml in more than one sample.

These suggested guidelines are an attempt to limit disease outbreaks. The problem lies in the validity of the test to indicate pathogenic substances present. For example, all of the wells sampled, except Well 4 and Well 7, were at some time used for human consumption (though some not by infants). Yet no known specific disease outbreak could be documented as a result of contaminated well water.

Other difficult areas in predicting ground water pollution includes false test information due to sampling, experimental, or clerical errors. A probable sampling error occurred on April 12, 1979, where Well 7 reported 1,400 coliform colonies per 100 ml in contrast to the normal zero counts. This case points out that a "safe" well may exceed the standards due to inaccurate sampling of the indicator organism.

Craun and McCabe (6) reviewed the causes of waterborne disease outbreaks and concluded that most ground water related disease outbreaks occurred in private systems where improper well construction or location was evident. This suggests the need for well guidelines and regulations to limit the source of the contamination before a disease outbreak actually occurs.

## Well Survey

The well structure and formation are directly related to the quality of well water. Adequacy of well construction in terms of water quality protection can be shown by the testing parameters used to indicate contamination. The bacterial and nitrogen levels are summarized in Table 6 for the 14 wells tested. The use of this summary and the description of each well presented in Table 5 gives valuable information on the causes of well contamination.

Upon looking at Table 6, it is evident that augered wells experience more water quality problems than drilled or grouted augered wells. The mean bacterial valves of 100 colonies per 100 ml or greater for augered wells far exceeds the recommended guidelines. Wells 1-5 were "unsafe" the majority of the sampling period as shown by bacteria and nitrate levels. The reasons for the poor water quality can be related to the actual well construction and location of each well.

Table 5 shows that for Wells 1-6 the chief construction defect noted was the lack of sanitary protection or seal or location too near a known pollution source. For example, Well 1 with a loose metal cover and cracks in the casing does not stop surface drainage from entering. The contaminants from a nearby feedlot would flow directly into this well and pollute the ground water. This fact is shown by the high total coliform counts (mean value at 109 colonies per 100 ml), high fecal streptococci counts (mean at 141 colonies per 100 ml), and high nitrate levels (mean at 26.9 mg/l as N). Similar findings for Wells 2-6 show the lack of proper well structure and location.

The drilled wells show much lower mean values for bacteria and nitrate tests than for the augered wells. Wells 6 and 7 show a much lower percentage of unsafe samples

Table 6. Summary of the test results for Wells 1-14.

| Well Number | Total Number of Samples | Total Coliform Results mean[a] | Total Coliform Results % unsafe[b] | Fecal Strep. Results mean | Fecal Strep. Results % unsafe[b] | Nitrate Results mean | Nitrate Results % unsafe[c] |
|---|---|---|---|---|---|---|---|
| Augered Wells | | | | | | | |
| 1 | 26 | 109 | 80% | 141 | 84% | 26.9 | 100% |
| 2 | 25 | 323 | 83% | 353 | 83% | 9.7 | 54% |
| 3 | 25 | 800 | 83% | 238 | 88% | 12.6 | 100% |
| 4 | 24 | 431 | 75% | 504 | 88% | 15.8 | 96% |
| 5 | 26 | 147 | 81% | 105 | 62% | 50.9 | 100% |
| Augered Wells Grounted to 10 feet | | | | | | | |
| 8 | 3 | 1.3 | 0% | 0 | 0% | 1.9 | 0% |
| 9 | 3 | 3.7 | 33% | 5.3 | 33% | 4.7 | 0% |
| 10 | 1 | 56 | 100% | 12 | 100% | 4.8 | 0% |
| 11 | 1 | 2 | 0% | 0 | 0% | 4.6 | 0% |
| 12 | 1 | 0 | 0% | 0 | 0% | 2.9 | 0% |
| 13 | 1 | 0 | 0% | 0 | 0% | 0.2 | 0% |
| 14 | 2 | 0.5 | 0% | 0.50 | 0% | 8.6 | 0% |
| Drilled Wells | | | | | | | |
| 6 | 24 | 26.1 | 44% | 85.9 | 50% | 6.7 | 46% |
| 7 | 23 | 0.27 | 83% | 6.7 | 21% | 0.75 | 0% |

[a]Arithmetic mean of all samples taken.

[b]Percent of samples that exceed 4 colonies per 100 ml.

[c]Percent of samples that exceed 10 mg/l nitrate (as N).

than augered wells, yet they are not pollution free. Both wells are located in a cement pit. Well 6, with higher mean values for all tests than Well 7, has problems with surface water flowing into the pit and then entering the well through a poor sanitary seal on the casing. This suggests that the well pit offers access for pollutants to enter the water supply.

Another interesting point shown in Table 6 is that Wells 2, and 7-14 show much lower mean nitrate values than the other augered and drilled wells. This can be explained by comparing the distances of each well to a potential pollution site. Wells 2, and 7-14 are located such that these distances are much greater than the other wells and their nitrate levels are subsequently lower. This suggests that location of the well is important in keeping nitrate pollution at safe levels.

Wells 8-14 show much better water quality than the other wells. These augered wells are grouted to 10 feet and show no indication of pollution sources nearby that would affect water quality. Though only up to three samples were taken, the bacteria and nitrate levels show that these wells generally meet recommended criteria in a large percentage of the sampling tests. The mean values of the three tests are significantly lower when compared to the other augered wells without grouting. It seems that the grouting of a well will stop the surface contaminant's travel by blocking their transmission pathways into the well. This is significant because a large portion of pollution comes from surface contaminants.

Wells 1 and 5 were shock chlorinated in the fall of 1978 to determine if disinfection had any long term effects on the microbial water quality. The chlorine gave protection up to 1 to 2 weeks in these wells (Figures 8 and 12), yet eventually the bacterial counts increased again to high numbers.

The poor results of chlorination after 2 weeks indicate that the pollution mechanism is still evident after the initial total bacterial kill. The rebound in Well 1 can be explained because of the poor construction allowing surface drainage from a nearby feedlot to again enter the well, thereby providing a frequent source of new bacteria into the ground water. Well 5 shows no major construction defects, but was built near a collasped well. This allows runoff from silage storage area and feedlot to flow into the well. The wide fluctuations in bacterial counts show that shock chlorination is not a long term solution for poor water quality due to construction problems in these wells.

# CONCLUSIONS AND RECOMMENDATIONS

It is apparent that the problems of ground water contamination are highly complex. All factors involved in an individual case must consider the hydraulics of the flow system, the chemical, physical, and biological nature of the contaminant, the natural removal or degradation processes that can be expected to operate in the underground environment, and the geologic factors. In actual shallow aquifer development and management programs, failure to consider each of these factors may result in the contamination of primary or even alternate sources of supply.

The research investigation described in this report supports the following conclusions concerning the variations in water quality in rural Iowa wells:

1) There are a large number of wells that have below standard water quality in rural Iowa, in terms of coliform bacteria and nitrate nitrogen levels.

2) Seasonal variations, like precipitation and temperature, play a significant role in determining the bacterial quality of a well.

3) Large seasonal fluctuations in water quality in wells were observed in those monitored in this research study. This points out a need for a more frequent sampling in order to determine the quality of water in many wells.

4) Most of the wells that show poor water quality can be related to the type of construction used. Dug or augered wells that are not grouted tend to experience more problems than drilled or driven wells.

5) The grouted wells that were monitored show much less variation in water quality than the ungrouted wells.

6) Entry of the contaminant involves three factors: a) the contaminant source, b) a transmission path, and 3) a transmitting fluid. Proper well construction and location measures are important to prevent pollution entry.

7) Certain construction practices like grouting to 10 feet, the use of pitless adaptors, a disinfection step, and large distances from potential pollution sources can help insure a safe well water supply.

8) The dug and augered wells which show large fluctuations in water quality can provide an adequate water supply if given special consideration in construction and protection methods.

The concern for "safe" water supplies has shown the need for contamination-free well water. The problem area lies in what can be done to eliminate or reduce the number of instances in which contamination occurs. Water quality improvement should begin with first excluding water of undesirable quality from the source of supply. Next, concern in keeping existing supplies free from pollutants must be dealth with by regulations or quidelines imposed to insure water quality.

Minimum water well design and construction standards are needed so the problems associated with water supplies are minimized. The water well, for example, offers many possible avenues for pollution to enter the aquifer and degrade existing water supplies. Regulations and guidelines must cover all aspects of well design, construction, location, completion, reconstruction, and disinfection to help insure uniform water quality.

The state or county health boards are in a position to regulate and impose standards needed to control ground water contamination. Guidelines and restrictions must be placed on all phases of well construction, completion, location, abandonment, and other related areas. If the standards are enforced, the percentage of "unsafe" wells in Iowa will be reduced. This enforcement would require additional manpower as not all Iowa counties have personnel available.

The need for controlling pollutants in well water supplies involves more than just regulations on well construction. Other areas where guidelines are needed include the well location and land use policies in the vicinity of well water supplies. For example, the horizontal and vertical protective distances from known pollutant sources (such as cess pools and abandoned wells) to the well must be determined quantitatively, so that their effects on water quality are minimized. There needs to be practical limits set on well location so that consistent levels of safety might be achieved.

Also other areas where standards are needed include the effective identification, detection, toxcity, and pathogenicity of pollutants in water well supplies. The difficulty arises in recognizing when a pollutant reaches a level to signify when action should be taken. Further knowledge of the nature and behavior of the contaminants can provide important clues in determining the difficulties in the sanitary protection of the well.

The education of persons or the public directly involved with the well water is important when safeguarding water supplies. Recognizing a potential contaminant source or possible preventative measures in well construction is difficult unless a person is educated in the subject. The well drillers' education on guidelines and proper procedures for well construction might prove worthwhile in improving and maintaining high standards for new wells. Other information taught to the public on the subject and the indication of possible pollutants may prove to be invaluable.

When evaluating the "what can be done?" aspect of ground water pollution, mention must be made in all areas pertaining to the water well. In addition to the well construction and location standards, special areas like geologic formations, hydraulic characteristics of the well, testing procedure used, sampling programs, and numerous others must be evaluated to determine their effects on well water pollution. So it is very difficult to differentiate a safe well from one that is polluted, especially at various times of the year. Sampling a well is encouraged to be taken more than once during the fall and spring months in Iowa.

Recommendations for future study includes the additional sampling of the grouted wells to show that fewer water quality problems occur as compared to ungrouted wells. Also the reconstruction of poorly constructed wells to determine of any significant water quality changes appear would be useful if the time and money were available.

REFERENCES

1. Allen, M.J. and S.M. Morrison. "Bacterial movement through fractured bedrock." Ground Water, 11, No. 2 (1973), 6-10.

2. Allen, M.J., and Geldreich, E.E. "Bacteriological criteria for ground water quality." Proc. 2nd National Ground Water Quality Symposium, Sept. 25, 1974.

3. Bernhart, A.P. "Protection of water supply wells from contaminants." Ground Water, 2, No. 3 (1973), 9.

4. California State Resources Agency. "Recommended minimum well construction and sealing standards for protection of ground water quality." Calif. State Resources Agency Bulletin No. 74, July, 1962.

5. Clarke, N.A., and Chang, S.L. "Enteric viruses in water." J. Am. Water Works Assoc., 51, (1959), 1299.

6. Craun, G.F., and McCabe, L.J. "Review of the causes of waterborne disease outbreaks." J. Am. Water Works Assoc., 65, No. 1 (1973), 74-84.

7. Deutsch, M. "National controls involved in shallow aquifer contamination." Ground Water, 3, No. 3 (1965), 37-40.

8. Donahue, W.E. "Cyanosis in infants with nitrates in drinking water." Pediatrics, 3, (1949), 308.

9. Editors of Water Well Journal. "Ground water pollution from subsurface excavations." Water Well J., 28, (1974), 45.

10. Edwards, D.M., and Fischbach, P.E., and Young, L.I. "Movement of nitrates under irrigated agriculture." Transactions Amer. Soc. Agr. Eng., 15, (1972), 73-75.

11. Gibson, U.P., and Singer, R.D. Water Well Manual. Berkeley, CA: Premier Press, 1971.

12. Gillham, R.W., and Webber, L.R. "Nitrogen contamination of ground water by barnyard leachates." J. Water Pollut. Control Fed., 41, No. 10 (1969), 1759.

13. Gormly, J.R., and Spalding, B. "Sources and concentrations of nitrate nitrogen in ground water of the central Platte region, Nebr." Ground Water, 17, No. 3 (1979), 291-301.

14. Iowa Dept. of Health. "Sanitary standards for water wells." Environmental Eng. Service, Des Moines, IA, 1971.

15. Jones, E.E. "Where does water quality improvement begin?" Ground Water, 9, No. 3 (1971), 24.

16. Jones, E.E. "Evaluating well construction." J. Environ. Health, 36, No. 6 (1974), 554-560.

17. Jones, E.E., and Murray, C.N. "Improving the sanitary protection of ground water in severely folded, fractured, and creviced limestone." Ground Water, 15, (1977), 66.

18. Kabler, B. and Clark, C. "Coliform group and fecal coliform organisms as indicators of pollution in drinking water." J. Am. Water Works Assoc., 52, (1960), 1577.

19. Kaufman, W.J. "Chemical pollution of ground water." J. Am. Water Works Assoc., 66, No. 3 (1974), 152.

20. Lance, J.C. "Nitrogen removal by soil mechanisms." J. Water Pollut. Control Fed., 44, (1972), 1352.

21. Lindorff, D.E. "Ground water pollution - a status report." Ground Water, 17, No. 1 (1979), 9-17.

22. Legrand, H.E. "Role of ground water contamination in water management." J. Am. Water Works Assoc., 59. (1967), 557.

23. Lehr, J.H. "Ground water - an imperative in water resource planning." Proc. 14th Conf. on Water Quality, 14, (1972), 1.

24. McFeters, E.R. "Comparative studies of indicator bacteria and enteric pathogens on well waters." Applied Microbiology, 27, (1974), 823.

25. McNabb, J.E., and Dunlap, W.J. "Subsurface biological activity in relation to ground water pollution." Proc. 2nd National Ground Water Quality Symposium, Sept. 25, 1974.

26. Miller, L.W. "Methemoglobinemia associated with well water." J. Am. Med. Assoc., 216, No. 10 (1971), 1642.

27. Nightingale, H.I. "Nitrates in soil and ground water beneath irrigated and fertilized crops." Soil Science, 114, (1972), 300.

28. Preul, H.C. "Underground movement of nitrogen." J. Water Pollut. Control Fed., 40, No. 1 (1966), 335.

29. Preul, H.C. and Schroepfer, G.J. "Travel of nitrogen in soils." J. Water Pollut. Control Fed., 40, No. 1 (1968), 30-48.

30. Ritter, C. and Hausler, W.J. "Yearly variation in sanitary quality of well water." Am. J. Public Health, 5, No. 9 (1961), 1347-1357.

31. Romero, J.C. "The movement of bacteria and virus through porous media." Ground Water, 8, No. 2 (1970), 37.

32. Sandhu, S.S. "Inorganic contaminants in rural drinking waters." J. Am. Water Works Assoc., 69, No. 4 (1977), 219-222.

33. Sepp, E. "Nitrogen cycle in ground waters." Bur. of San. Eng., State of Calif., Dept. of Public Health, Los Angeles, CA, 1970.

34. Standard Methods for the Examination of Water and Wastewater. 14th Ed. Washington, D.C.: American Public Health Assoc., 1975.

35. Tryon, C.P. "Ground water quality variation in Phelps County, Missouri." Ground Water, 14, No. 4 (1976), 214-223.

36. U.S. Dept. of Commerce. "Iowa climatological data." vol. 89-90. Asheville, N.C.: National Climatic Center, 1978-1979.

37. U.S. Environmental Protection Agency. "Impact of abandoned wells on ground water." EPA-600/3-77-095. 1977.

38. U.S. Environmental Protection Agency. "Manual of individual water supply systems." EPA Water Supply Division EPA-430-9-73-003, 1973.

39. Walker, W.H. "Ground water nitrate pollution in rural areas." Ground Water, 2, No. 5 (1973), 19-22.

40. Wood, L.A. "Ground water degradation - causes and cures." Proc. 14th Conf. on Water Quality, 14 (1972), 17.

41. Young, C.P. "Prediction of future nitrate concentrations in ground water." Ground Water, 14, No. 6 (1976), 426-437.

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## APPENDIX A

Water sampling procedures

The purpose of the sampling procedure is to obtain a representative water sample to give an indication of possible pollution in the well system (for both bacterial and chemical sampling).

Procedures:

1. Conduct site survey and note distances to pollution sources and well construction.
2. Interview with well owner (or possible well driller) and obtain as much information about the well and its use. Record data.
3. Choose a sampling tap:

   a) If drinking water is ordinarily obtained from the kitchen sink faucet, and it is a swinging faucet which mixes hot and cold water, do not sample from this faucet. (Take sample from a faucet which is stationary. Might be bathroom or some sink or other faucet which is not a swing type.)

   b) If water softener is in use, test at the faucet (after water has been softened, if this is the water you drink.)

   c) If a sampling tap is not obtainable inside the house use a hydrant where water is being used for consumption.

4. Flame the exterior of the water tap for at least 2 minutes (e.g. a good cigarette lighter).

5. Run water 2-3 minutes before sample taken.

6. Fill two sample bottles per well.

   a) One bottle (sterilized 16 oz. bottle) for bacterial samples by uncapping of bottle without touching inside of cap or bottle lid.

   b) One bottle (4 oz., clean) for nitrite + nitrate nitrogen sample.

7. Fill bottles with water until ½" of the top of the bottle, then recap immediately.

8. Store sample bottles until submitting to laboratory for analysis:

   a) The bacterial samples must be kept cool (40-45$^{o}$F) by placing in an ice chest.

   b) The nitrate samples are preserved with 3-4 drops of concentrated sulfuric acid.

9. Submit samples to testing laboratory:

   a) Bacterial samples to Veterinary Diagnostic Laboratory at Iowa State University.

   b) Nitrogen samples to the Analytical Services Laboratory of the Engineering Research Institute at Iowa State University.

# APPENDIX B

Procedures for shock chlorination

Wells 1 and 5

"Shock" chlorination is a "one-shot" disinfection of a well, as contrasted to continuous chlorination by manufactured devices. Chlorination will kill bacteria; it will do nothing for nitrates in the water. Shock chlorination is recommended for:

a) newly constructed wells or old wells that have been opened for repair, to kill organisms that may have been introduced, or

b) wells whose tests show presence of coliform or iron bacteria.

Procedure:

1. The chlorine source used in disinfection was High Test Calcium Hypochlorite (HTH) at 65% available chlorine. Suggested dosage at .25 lb. per 100 gallons of water.
2. Determine well gallonage and amount of chlorine to be added.

a) Well 1

| | |
|---|---|
| Well diameter | 30 inches (at 37 gal/ft of well) |
| Well gallonage | 780 gallons |
| HTH Chlorine added | 2.75 lbs. (including 1 lb. excess) |

b) Well 5

| | |
|---|---|
| Well diameter | 30 inches |
| Well gallonage | 360 gallons |
| HTH Chlorine added | 20 lbs. (including 1 lb. excess) |

3. Addition of chlorine involves placing of granular HTH in measured amount inside of a weighed porous sack (burlap material). This sack is then raised and lowered within the entire water depth until the granules are dissolved.

4. Recirculate the chlorinated well water out of and back into the well (for 30 minutes) by attaching a hose to a nearby faucet or hydrant; making sure that all inside surfaces of the well are washed down. The returning water must have a strong chlorine odor; if not, add more.

5. Disinfect the distribution system by flushing all connecting lines and tanks until a strong chlorine odor is detected.

6. Let chlorinated system stand for 2 hours.

7. Flush out the chlorinated water by letting water run into a ditch, or waterway.

    a) Well 1 flushed for 10 hours.

    b) Well 5 flushed for 4½ hours.

8. Retest the water for bacteria.

# APPENDIX C

## RESULTS OF TESTING PROGRAM

Table C1. Results of total coliform bacteria testing program for wells 1-7.

| Date (mo/d) | Well No. 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Total Coliform / 100 ml | | | | | | | |
| 8/21 | -[a] | 2600 | - | - | 192 | - | - |
| 8/22 | 670 | - | - | - | 270 | - | - |
| 10/5 | 308 | 108 | 0 | 144 | 236 | 84 | 0 |
| 10/12 | 240 | TNTC[b] | TNTC | 0 | TNTC | TNTC | 0 |
| 10/20 | 150 | 640 | 2800 | 200 | 100/0[c] | 240 | 0 |
| 10/26 | 160 | 370 | 620 | 264 | 0 | 54 | 0 |
| 11/2 | 102 | 180 | 550 | 180 | 560 | 30 | 6 |
| 11/9 | 56 | 100 | 670 | 130 | 30 | 56 | 0 |
| 11/16 | 52/0[c] | 50 | 560 | 270 | TNTC | 0 | 0 |
| 11/20 | 0 | - | 710 | 1000 | 850 | 1 | 0 |
| 11/30 | 62 | 700 | 690 | 110 | 520 | 0 | 0 |
| 12/13 | 44 | 88 | 300 | 4 | 70 | 0 | 0 |
| 12/20 | 42 | 44 | 194 | 10 | 4 | 0 | 0 |
| 1/18 | 4 | 0 | 6 | 0 | 8 | 30 | 0 |
| 2/1 | 0 | 20 | 14 | 0 | 0 | 0 | 0 |
| 2/14 | 2 | 0 | 0 | 0 | 2 | 0 | 0 |
| 2/28 | 2 | 0 | 2 | 0 | 0 | 2 | 0 |
| 3/7 | 20 | 0 | 0 | 380 | 8 | 0 | - |
| 3/15 | 90 | 28 | TNTC | 84 | 112 | 0 | 0 |
| 3/22 | 160 | 40 | TNTC | 80 | 112 | 0 | 0 |
| 3/29 | 240 | 34 | TNTC | 88 | 54 | 0 | 0 |
| 4/5 | 128 | 410 | 2080 | 42 | 16 | 58 | 0 |
| 4/12 | TNTC | 560 | TNTC | 1440 | 340 | TNTC | 1400 |
| 4/26 | 54 | 46 | 2400 | 4960 | 16 | 20 | 0 |
| 5/10 | 28 | 480 | 1680 | TNTC | 10 | 0 | 0 |
| 5/17 | 12 | 930 | 1920 | 520 | 6 | 0 | 0 |

[a]Test not performed.

[b]Too numerous to count.

[c]Well shock chlorinated on this date (before/after).

Table C2. Results of fecal streptococci bacteria testing program for wells 1-7.

| Date (mo/d) | Well No. 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Fecal Streptococci / 100 ml | | | | | | | |
| 8/21 | -[a] | 2800 | - | - | 30 | - | - |
| 8/22 | 150 | - | - | - | 6 | - | - |
| 10/5 | 216 | 372 | 676 | 652 | 488 | 540 | 60 |
| 10/12 | TNTC | 456 | 240 | 940 | 704[c] | TNTC[b] | 32 |
| 10/20 | 520 | 3300 | 1160 | 1200 | 150/2[c] | 150 | 21 |
| 10/26 | 720 | 640 | 620 | 620 | 0 | 120 | 8 |
| 11/2 | 176 | 410 | 530 | 790 | 180 | 110 | 4 |
| 11/9 | 330[c] | 94 | 240 | 490 | 50 | 12 | 4 |
| 11/16 | 200/0[c] | 24 | TNTC | 540 | 168 | 0 | 0 |
| 11/20 | 8 | - | 388 | 1160 | 74 | 0 | 16 |
| 11/30 | 4 | 96 | 460 | 3120 | 14 | 20 | 0 |
| 12/13 | 2 | 10 | 26 | 18 | 0 | 4 | 0 |
| 12/20 | 240 | 64 | 194 | 0 | 0 | 420 | 0 |
| 1/18 | 28 | 0 | 24 | 36 | 0 | 20 | 0 |
| 2/1 | 28 | 0 | 136 | 160 | 0 | 8 | 0 |
| 2/14 | 0 | 2 | 66 | 0 | 0 | 0 | 0 |
| 2/28 | 0 | 2 | 4 | 0 | 0 | 0 | 0 |
| 3/7 | 5 | 14 | 0 | 12 | 2 | 0 | - |
| 3/15 | 92 | 12 | 300 | 132 | 104 | 0 | 0 |
| 3/22 | 118 | 32 | 150 | 280 | 240 | 0 | 0 |
| 3/29 | 290 | 34 | 58 | 300 | 440 | 0 | 0 |
| 4/5 | 100 | 46 | 40 | 960 | 36 | 52 | 0 |
| 4/12 | 62 | 12 | 2 | 28 | 26 | 520 | 0 |
| 4/26 | 18 | 30 | 116 | 550 | 0 | 0 | 0 |
| 5/10 | 44 | 24 | 38 | 88 | 2 | 0 | 0 |
| 5/17 | 36 | 6 | 22 | 8 | 8 | 0 | 0 |

[a]Test not performed.

[b]Too numerous to count.

[c]Well shock chlorinated on this date (before/after).

Table C3. Results of the nitrite + nitrate nitrogen testing program for wells 1-7

| Date | Well No. | | | | | | |
|---|---|---|---|---|---|---|---|
| (mo/d) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Nitrite + Nitrate: Nitrogen (mg/1 as N) | | | | | | | |
| 8/21 | -[a] | 10.2 | - | - | 51.0 | - | - |
| 8/22 | 10.4 | - | - | - | 51.2 | - | - |
| 10/5 | 29.0 | 8.5 | 14.7 | 14.8 | 80.3 | 19.9 | .08 |
| 10/12 | 24.4 | 10.8 | 13.8 | 13.6 | 68.1 | 13.0 | .03 |
| 10/20 | 54.3 | 9.0 | 16.2 | 16.6 | 60.3 | 16.1 | .90 |
| 10/26 | 26.5 | 10.9 | 13.3 | 19.0 | 57.3 | 13.0 | .74 |
| 11/2 | 28.5 | 10.3 | 12.4 | 20.6 | 48.5 | 10.3 | 1.32 |
| 11/9 | 22.5 | 10.7 | 12.1 | 17.7 | - | 1.6 | 1.13 |
| 11/16 | 24.0 | 11.0 | 11.8 | 22.4 | 49.6 | .4 | .28 |
| 11/20 | 27.3 | - | 10.7 | 23.6 | 48.7 | .9 | .03 |
| 11/30 | 27.0 | 8.8 | 11.1 | 18.7 | 49.6 | .3 | .11 |
| 12/13 | 24.1 | 10.4 | 11.0 | 16.7 | 35.2 | .3 | .33 |
| 12/20 | 27.3 | 11.3 | 11.5 | 16.3 | 49.3 | .4 | .09 |
| 1/18 | 26.7 | 11.8 | 10.9 | 17.9 | 39.5 | .1 | .09 |
| 2/1 | 27.0 | 11.6 | 10.4 | 17.2 | 37.9 | .1 | .19 |
| 2/14 | 29.9 | 13.4 | 11.6 | 18.7 | 38.2 | .3 | .31 |
| 2/28 | 30.9 | 12.2 | 11.5 | 11.6 | 36.3 | .1 | .18 |
| 3/7 | 31.3 | 11.2 | 12.0 | - | 32.7 | .1 | - |
| 3/15 | 27.6 | 6.1 | 12.1 | 5.2 | 35.9 | .1 | .10 |
| 3/22 | 28.6 | 11.2 | 12.6 | 11.8 | 31.8 | 15.0 | .09 |
| 3/29 | 27.7 | 7.3 | 13.6 | 12.4 | 62.4 | 13.2 | .08 |
| 4/5 | 25.7 | 6.9 | 12.9 | 12.4 | 69.0 | 16.9 | .06 |
| 4/12 | 26.4 | 6.8 | 14.7 | 12.0 | 69.2 | - | .08 |
| 4/19 | 26.0 | 6.9 | 14.3 | 11.5 | 66.3 | 12.2 | .05 |
| 4/26 | 27.0 | 8.1 | 12.7 | 13.1 | 51.1 | 11.5 | .48 |
| 5/10 | 15.4 | 6.2 | 11.2 | 14.8 | 60.2 | 17.1 | .10 |
| 5/17 | 23.6 | 7.6 | 11.8 | 15.7 | 59.8 | 8.7 | - |

[a]Test not performed.

Table C4. Results of two Iowa counties testing programs showing water quality as relating to type of well construction.

| County | Date | Type of Well | Coliform Test Results No. | Coliform Test Results Passed[a] | Coliform Test Results Exceed Std. | Nitrate Test Results No. | Nitrate Test Results Passed | Nitrate Test Results Exceed Std. |
|---|---|---|---|---|---|---|---|---|
| Ida | 1977 | Dug | 87 | 4 | 83 | 100 | 79 | 21 |
| | | Augered | 33 | 4 | 29 | 38 | 26 | 12 |
| | | Drilled | 10 | 5 | 5 | 11 | 7 | 4 |
| | | Driven | 27 | 19 | 8 | 37 | 35 | 2 |
| Plymouth | 1977 | Dug | 11 | 6 | 5 | 16 | 12 | 4 |
| | | Augered | 37 | 12 | 25 | 44 | 29 | 15 |
| | | Drilled | 4 | 4 | 0 | 3 | 3 | 0 |
| | | Driven | 37 | 34 | 3 | 41 | 41 | 0 |

[a]Meets EPA criteria of 0 coliform colonies per 100 ml.

[b]Meets EPA criteria of less than 10 mg/1 nitrate (as N).

Table C5. Summary of testing parameters performed on wells 9-14 (which are grouted to 10 feet and show no major construction defects).

| Date (mo/d) | Well No. 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| **Total Coliforms / 100 ml** | | | | | | | |
| 5/2 | 0 | 2 | 56 | 2 | 0 | 0 | -[a] |
| 5/10 | 4 | 3 | - | - | - | - | 0 |
| 5/17 | 0 | 6 | - | - | - | - | 1 |
| **Fecal Streptococci / 100 ml** | | | | | | | |
| 5/2 | 0 | 3 | 12 | 0 | 0 | 0 | - |
| 5/10 | 0 | 1 | - | - | - | - | 0 |
| 5/17 | 0 | 12 | - | - | - | - | 1 |
| **Nitrite + Nitrate: Nitrogen (mg/l as N)** | | | | | | | |
| 5/2 | 1.7 | 5.04 | 4.8 | 4.6 | 2.9 | .21 | - |
| 5/10 | 2.0 | 4.70 | - | - | - | - | 3.51 |
| 5/17 | 1.9 | 4.40 | - | - | - | - | 13.60 |

[a]Test not performed.

# APPENDIX D

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 1 DATE 6/1/79

ADDRESS Poweshiek Co.

WELL LOCATION ____ (Town) ____ (County) ____ (Township)

1. Depth of well 48 feet augered
2. Ground water: Static Level 16' Max ____ Min ____ Average ____
3. Casing: Diameter 30 in. Depth 48' Material cement tile
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make none Description ____ Material ____
   Electrical line inlet sealed - Yes ____ No X
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material none Average thickness ____ Depth ____
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material metal cover Condition poor
   Sloped away from well - Yes ____ No X
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location basement Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination ____ Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard 3' Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well 30' Other source of potential contamination ____

COMMENTS: Surface drainage enters the well from cracks in the soil around the casing through tile joints.

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 2 DATE 6/1/79

ADDRESS Poweshiek Co.

WELL LOCATION ______ (Town) ______ (County) ______ (Township)

1. Depth of well 23' augered

2. Ground water: Static Level 10' Max ______ Min ______ Average ______

3. Casing: Diameter 30' Depth 23' Material cement tile

4. Well screen: Depth ______ Desceiption ______

5. Sanitary casing seal or cap: Make none Description ______ Material ______
   Electrical line inlet sealed - Yes ______ No x

6. Casing vent: Description ______ Screened - Yes ______ No ______

7. Grouting: Material none Average thickness ______ Depth ______

8. Pump: Setting ______ Recom. setting ______ Description ______
   Make ______ Capacity < 10 (gpm) Drawdown ______

9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ______

10. Pitless adapter or other underground discharge: Make ______
    Description ______

11. Storage: Location basement Material ______
    Capacity ______ Pressure ______

12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ______ Walls ______ Top ______
    Description of manhole & cover ______
    Pit drained by - Gravity ______ Sump with pump ______
    Floor sloped to drain or sump - Yes ______ No ______
    Outlet location ______ Screened - Yes ______ No ______

13. Disinfection : Chlorination never Other ______
    Type of equipment ______
    Point of connection - Before storage ______ After storage ______

14. Distance of well from: Septic tank 20' Lateral field ______ Privy ______
    Leaching pit ______ Barnyard 50' Sewage lagoon ______
    Drain tile ______ Sink hole ______ Sewer lines ______
    Abandoned well 15' Other source of potential contamination ______

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 3 DATE 6/1/79

ADDRESS Pwoeshiek Co.

WELL LOCATION ________ (Town) (County) (Township)

1. Depth of well 20' augered
2. Ground water: Static Level ____ Max ____ Min ____ Average ____
3. Casing: Diameter 36' Depth ____ Material ____
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make none Description ____ Material ____
   Electrical line inlet sealed - Yes ____ No x
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material none Average thickness ____ Depth ____
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material wooden Condition poor
   Sloped away from well - Yes ____ No x
10. Pitless adapter or other underground discharge: Make ____
   Description ____
11. Storage: Location none Material ____
   Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
   Material - Floor ____ Walls ____ Top ____
   Description of manhole & cover ____
   Pit drained by - Gravity ____ Sump with pump ____
   Floor sloped to drain or sump - Yes ____ No ____
   Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination never Other ____
   Type of equipment ____
   Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank 10' Lateral field ____ Privy ____
   Leaching pit ____ Barnyard 50' Sewage lagoon ____
   Drain tile ____ Sink hole ____ Sewer lines ____
   Abandoned well ____ Other source of potential contamination ____

COMMENTS: Cracks in the wooded cover allow pollutants to enter

IOWA STATE DEPARTMENT OF HEALTH

**PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET**

OWNER Well 4 DATE 6/1/79

ADDRESS Poweshiek Co.

WELL LOCATION ______ (Town) (County) (Township)

1. Depth of well 20' augered
2. Ground water: Static Level ____ Max ____ Min ____ Average ____
3. Casing: Diameter 36" Depth ____ Material cement
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
   Electrical line inlet sealed - Yes ____ No x
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material none Average thickness ____ Depth ____
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material wooden Condition poor
   Sloped away from well - Yes ____ No x
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location ____ Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination never Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard 0' Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well ____ Other source of potential contamination located in barnyard

COMMENTS: Cracks in the wooden cover are noted

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 5 DATE 6/1/79

ADDRESS Poweshiek Co.

WELL LOCATION ________ (Town) ________ (County) ________ (Township)

1. Depth of well 38' augered
2. Ground water: Static Level ____ Max ____ Min ____ Average ____
3. Casing: Diameter 30" Depth 34' Material cement tile
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
   Electrical line inlet sealed - Yes ____ No ____
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material none Average thickness ____ Depth ____
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes ____ No x
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location basement Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination ____ Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard 30' Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well 25' Other source of potential contamination located near collapsed well bore

COMMENTS: Channels in the soil around the casing allows runoff to percolate down to reach tile joints

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 6 DATE 6/1/79

ADDRESS Poweshiek Co.

WELL LOCATION ______ (Town) ______ (County) ______ (Township)

1. Depth of well ?? drilled
2. Ground water: Static Level ______ Max ______ Min ______ Average ______
3. Casing: Diameter 6" Depth ______ Material ______
4. Well screen: Depth ______ Desceiption ______
5. Sanitary casing seal or cap: Make ______ Description ______ Material ______
   Electrical line inlet sealed - Yes ______ No x
6. Casing vent: Description ______ Screened - Yes ______ No ______
7. Grouting: Material none Average thickness ______ Depth ______
8. Pump: Setting ______ Recom. setting ______ Description ______
   Make ______ Capacity ≤ 10 (gpm) Drawdown ______
9. Well platform: Material ______ Condition ______
   Sloped away from well - Yes ______ No ______
10. Pitless adapter or other underground discharge: Make ______
    Description ______
11. Storage: Location ______ Material ______
    Capacity ______ Pressure ______
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor cement Walls cement Top wooden
    Description of manhole & cover wooden cover in poor condition
    Pit drained by - Gravity ______ Sump with pump ______
    Floor sloped to drain or sump - Yes ______ No x
    Outlet location none Screened - Yes ______ No ______
13. Disinfection : Chlorination ______ Other ______
    Type of equipment ______
    Point of connection - Before storage ______ After storage ______
14. Distance of well from: Septic tank ______ Lateral field ______ Privy ______
    Leaching pit ______ Barnyard 5' Sewage lagoon ______
    Drain tile ______ Sink hole ______ Sewer lines ______
    Abandoned well ______ Other source of potential contamination ______

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 7 DATE 6/1/79

ADDRESS Poweshiek Co.

WELL LOCATION ______ (Town) (County) (Township)

1. Depth of well ?? drilled
2. Ground water: Static Level ______ Max ______ Min ______ Average ______
3. Casing: Diameter ______ Depth ______ Material ______
4. Well screen: Depth ______ Desceiption ______
5. Sanitary casing seal or cap: Make ______ Description ______ Material ______
   Electrical line inlet sealed - Yes ____ No ____
6. Casing vent: Description none Screened - Yes ____ No ____
7. Grouting: Material none Average thickness ______ Depth ______
8. Pump: Setting ______ Recom. setting ______ Description ______
   Make ______ Capacity < 10 (gpm) Drawdown ______
9. Well platform: Material ______ Condition ______
   Sloped away from well - Yes ______ No ______
10. Pitless adapter or other underground discharge: Make ______
    Description ______
11. Storage: Location ______ Material ______
    Capacity ______ Pressure ______
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor cement Walls cement Top cement
    Description of manhole & cover dry - good condition
    Pit drained by - Gravity ______ Sump with pump ______
    Floor sloped to drain or sump - Yes ______ No x
    Outlet location none Screened - Yes ______ No ______
13. Disinfection : Chlorination ______ Other ______
    Type of equipment ______
    Point of connection - Before storage ______ After storage ______
14. Distance of well from: Septic tank ______ Lateral field ______ Privy ______
    Leaching pit ______ Barnyard 30' Sewage lagoon ______
    Drain tile ______ Sink hole ______ Sewer lines ______
    Abandoned well ______ Other source of potential contamination ______

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 8 DATE 6/1/79

ADDRESS Polk Co.

WELL LOCATION ______ (Town) ______ (County) ______ (Township)

1. Depth of well 56', augered

2. Ground water: Static Level 16' Max ____ Min ____ Average ____

3. Casing: Diameter 31" Depth 56' Material cement tile

4. Well screen: Depth ____ Desceiption ____

5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
Electrical line inlet sealed - Yes x No ____

6. Casing vent: Description ____ Screened - Yes ____ No ____

7. Grouting: Material cement Average thickness 6" Depth 10'

8. Pump: Setting ____ Recom. setting ____ Description ____
Make ____ Capacity < 10 (gpm) Drawdown ____

9. Well platform: Material cement slab Condition good
Sloped away from well - Yes x No ____

10. Pitless adapter or other underground discharge: Make ____
Description ____

11. Storage: Location basement Material ____
Capacity ____ Pressure ____

12. Pit: (Pits are not approvable for new construction.)
Material - Floor ____ Walls ____ Top ____
Description of manhole & cover ____
Pit drained by - Gravity ____ Sump with pump ____
Floor sloped to drain or sump - Yes ____ No ____
Outlet location ____ Screened - Yes ____ No ____

13. Disinfection : Chlorination ____ Other ____
Type of equipment ____
Point of connection - Before storage ____ After storage ____

14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
Leaching pit ____ Barnyard ____ Sewage lagoon ____
Drain tile ____ Sink hole ____ Sewer lines ____
Abandoned well ____ Other somrce of potential contamination none noted

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 9 DATE 6/1/79

ADDRESS Polk Co.

WELL LOCATION ______ (Town) (County) (Township)

1. Depth of well 60' augered
2. Ground water: Static Level 19' Max ____ Min ____ Average ____
3. Casing: Diameter 30" Depth ____ Material cement tile
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
   Electrical line inlet sealed - Yes X No ____
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material cement Average thickness 6" Depth 10'
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ____
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location basement Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination ____ Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard ____ Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well ____ Other source of potential contamination none noted

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 10 DATE 6/1/79

ADDRESS Polk Co.

WELL LOCATION ____ (Town) ____ (County) ____ (Township)

1. Depth of well 60' augered
2. Ground water: Static Level 16' Max ____ Min ____ Average ____
3. Casing: Diameter 30" Depth ____ Material cement tile
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
   Electrical line inlet sealed - Yes x No ____
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material cement Average thickness 6" Depth 10'
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ____
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location basement Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination ____ Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard ____ Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well ____ Other source of potential contamination none noted

COMMENTS:

# IOWA STATE DEPARTMENT OF HEALTH

## PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 11 DATE 6/1/79

ADDRESS Dallas Co.

WELL LOCATION ______ (Town) ______ (County) ______ (Township)

1. Depth of well 100' augered
2. Ground water: Static Level ______ Max ______ Min ______ Average ______
3. Casing: Diameter 30" Depth ______ Material cement tile
4. Well screen: Depth ______ Desceiption ______
5. Sanitary casing seal or cap: Make ______ Description ______ Material ______
   Electrical line inlet sealed - Yes x No ______
6. Casing vent: Description ______ Screened - Yes ______ No ______
7. Grouting: Material cement Average thickness 6" Depth 10'
8. Pump: Setting ______ Recom. setting ______ Description ______
   Make ______ Capacity $< 10$ (gpm) Drawdown ______
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ______
10. Pitless adapter or other underground discharge: Make ______
    Description ______
11. Storage: Location basement Material ______
    Capacity ______ Pressure ______
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ______ Walls ______ Top ______
    Description of manhole & cover ______
    Pit drained by - Gravity ______ Sump with pump ______
    Floor sloped to drain or sump - Yes ______ No ______
    Outlet location ______ Screened - Yes ______ No ______
13. Disinfection : Chlorination ______ Other ______
    Type of equipment ______
    Point of connection - Before storage ______ After storage ______
14. Distance of well from: Septic tank ______ Lateral field ______ Privy ______
    Leaching pit ______ Barnyard ______ Sewage lagoon ______
    Drain tile ______ Sink hole ______ Sewer lines ______
    Abandoned well ______ Other source of potential contamination none noted

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 12 DATE 6/1/79

ADDRESS Dallas Co.

WELL LOCATION ____ (Town) ____ (County) ____ (Township)

1. Depth of well 110' Augered
2. Ground water: Static Level ____ Max ____ Min ____ Average ____
3. Casing: Diameter 32" Depth 110' Material cement tile
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
   Electrical line inlet sealed - Yes x No ____
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material cement Average thickness 6" Depth 10'
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ____
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location ____ Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination ____ Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard ____ Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well ____ Other source of potential contamination none noted

COMMENTS:

IOWA STATE DEPARTMENT OF HEALTH

PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 13 DATE 6/1/79

ADDRESS Dallas Co.

WELL LOCATION ______ (Town) (County) (Township)

1. Depth of well 67' augered
2. Ground water: Static Level 19' Max ____ Min ____ Average ____
3. Casing: Diameter 32" Depth 67' Material cement tile
4. Well screen: Depth ____ Desceiption ____
5. Sanitary casing seal or cap: Make ____ Description ____ Material ____
   Electrical line inlet sealed - Yes X No ____
6. Casing vent: Description ____ Screened - Yes ____ No ____
7. Grouting: Material cement Average thickness 6" Depth 10'
8. Pump: Setting ____ Recom. setting ____ Description ____
   Make ____ Capacity < 10 (gpm) Drawdown ____
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ____
10. Pitless adapter or other underground discharge: Make ____
    Description ____
11. Storage: Location basement Material ____
    Capacity ____ Pressure ____
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ____ Walls ____ Top ____
    Description of manhole & cover ____
    Pit drained by - Gravity ____ Sump with pump ____
    Floor sloped to drain or sump - Yes ____ No ____
    Outlet location ____ Screened - Yes ____ No ____
13. Disinfection : Chlorination ____ Other ____
    Type of equipment ____
    Point of connection - Before storage ____ After storage ____
14. Distance of well from: Septic tank ____ Lateral field ____ Privy ____
    Leaching pit ____ Barnyard ____ Sewage lagoon ____
    Drain tile ____ Sink hole ____ Sewer lines ____
    Abandoned well ____ Other source of potential contamination none noted

COMMENTS:

# IOWA STATE DEPARTMENT OF HEALTH

## PRIVATE & SMALL PUBLIC WATER WELL DATA SHEET

OWNER Well 14 DATE 6/1/79

ADDRESS Polk Co.

WELL LOCATION
(Town) (County) (Township)

1. Depth of well 99' augered
2. Ground water: Static Level ___ Max ___ Min ___ Average ___
3. Casing: Diameter 30" Depth 99' Material cement tile
4. Well screen: Depth ___ Desceiption ___
5. Sanitary casing seal or cap: Make ___ Description ___ Material ___
   Electrical line inlet sealed - Yes x No ___
6. Casing vent: Description ___ Screened - Yes ___ No ___
7. Grouting: Material cement Average thickness 6" Depth 10'
8. Pump: Setting ___ Recom. setting ___ Description ___
   Make ___ Capacity ≤ 10 (gpm) Drawdown ___
9. Well platform: Material cement slab Condition good
   Sloped away from well - Yes x No ___
10. Pitless adapter or other underground discharge: Make ___
    Description ___
11. Storage: Location basement Material ___
    Capacity ___ Pressure ___
12. Pit: (Pits are not approvable for new construction.)
    Material - Floor ___ Walls ___ Top ___
    Description of manhole & cover ___
    Pit drained by - Gravity ___ Sump with pump ___
    Floor sloped to drain or sump - Yes ___ No ___
    Outlet location ___ Screened - Yes ___ No ___
13. Disinfection : Chlorination ___ Other ___
    Type of equipment ___
    Point of connection - Before storage ___ After storage ___
14. Distance of well from: Septic tank ___ Lateral field ___ Privy ___
    Leaching pit ___ Barnyard ___ Sewage lagoon ___
    Drain tile ___ Sink hole ___ Sewer lines ___
    Abandoned well ___ Other source of potential contamination none noted

COMMENTS: